

#### LØN, LIN

These measurements give the mean and standard deviation of the primary and secondary search algorithms under noise alone. For both channels, the statistics are nearly constant as long as the receiver makes no misses. If the receiver makes misses, some signal energy enters into the statistic and the means of the variables increase.

Table 3.3 gives the statistics and compares them with those obtained independently with the RTHRS Program.

Table 3.3 Search Outputs under Noise (Table classified

Sear	ch Output		4	RECV			RTI	IRS	
	41.190.00	•	Me	<u> </u>	td Dev	1	<u>fean</u>	Std Dev	7_
	LØN		2.	/L	.12		2.94	,15	
	Lin		2.2	6	.17	2	2.59	.29	

Note that the statistics obtained by the receiver are lower than those obtained through the RTHRS program. No explanation of this result is currently available.

# SPEED, OFFSET

These variables are provided for operator convenience, but their standard deviations are worth noting. The maximum standard deviation in vessel speed is .02 Kts, which indicates rather accurate determination of the vessel speed. Similarly, the standard deviation of the frequency offset is about 1 mHz, which coincidently is the smallest step size on

the frequency synthesizer available to the project. When considered in conjunction with the time synchronization cabability of the system, the performance of the system in resolving the time and frequency uncertainty of the signal is excellent.

#### 4. Conclusions and Future Studies

- The performance of the M7BX3 version of the M7 communication system has been evaluated with simulated data corresponding to an ideal channel, CIDEAL, and a measured 350 min channel, CELTHRA. Examination of results at different S/Ns indicate that the system yields symbol error probabilities better than .0001 for S/Ns greater than -7dB, with no misses and essentially zero false alarms. Performance with CIDEAL is approximately 1 1/2 dB better than with CELTHRA. Examination of the statistics of various interval values indicate accurate time of arrival, Doppler effort and S/N measurements can be made. Further, the algorithms within the receiver are performing consistently and as expected.
- An at-sea evaluation of the system under controlled conditions and adequate duration is the <u>only</u> logical next step. Further system improvements and simulations should only be attempted with the benefit of actual sea results. The hardware and software have been ready for a year prior to this writing, consequently a sea evaluation could be quickly and economically performed.

### APPENDIX A

Detailed Specification of M7BX3A

## SYSTEM PARAMETERS

"BX38 - SPECIAL HIGH RATE VERSION FOR '78 NSUA LARGE ZSHLIM FOR HIGH SNR OPERATION NH0 = 16, INFO = NSUA-NUSC780 05 FEB 79 AT 0834 HR

ALPHABET SIZE, NA		64	
BLOCK LENGTH, NB		4096	
NO. OF BILATION BINS, ND		15	
OVERLAP COUNT, NE		2048	
'FOST-DETECTION BLANKING, NET		4096	
NO. OF SYMBOLS, NG		10	
SYNCH LP FILTER LENGTH, NHO		16	
TOORE LP FILTER LENGTH, NH1		?5€	
INTERPOLATION TABLE INTER-ZERO SIZE, NI		512	
NUMBER OF BITS / CHARACTER, NL		a	
TOTAL NUMBER OF LINES SEARCHED, NM		240	
ORDER OF INTERPOLATION, NO		32	
SYSTEM 0, NO		4	
SYMBOL LENGTH, NS		409	
LAST SYMBOL LENGTH, MSLAST		415	
PRIMARY FRACTIONAL LINE SHIFTS, NTO		2	
SECONDARY FRACTIONAL LINE SHIFTS, NT1		5	
NO. OF INTEGER FREQUENCY LINES / DILATION BIN, NH		16	
VERSE FLOO ( 1 = INVERSE 18 USED ), INVELO		ø	
NO. OF SISMAL LINES / PAGE, NSLPF		24	
" MBER OF FRIMARY SEARCHES / NOISE PRINT, MSINT		22	
CENTER FREQUENCY, F@ (KHZ,HZ,MHZ;16):	0	204	8

PRIMARY THRESHOLD, FTHRSQ 3.235 SECONDARY THRESHOLD, FTHR51 3.730 TYNCH RZ CUT LEVEL, RZRATO 0.100 PROBE RZ CUT LEVEL, RZRAT1 0.100 BOOT RE CUT LEVEL, RERATE 0.100 . \_CONDARY SEARCH HIDTH, DF1 1.00 BOOTSTRAP SEARCH WIDTH, DFZ 1.00 ZSH!FT LIMIT, ZSHLIM 0.500

CORRECT MESSAGE ( RADIX 40 ) : CORRECT MESSAGE ( HEX

NSUA-NUSC780

# APPENDIX B

SUMMARY SHEETS FROM M7BX3A SIMULATION

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196: 17: 58 ( 7: 43)
RECUR : 11 FEB 79A - BLOCK SUMMARY : 196: 19: 15 TO
M78X3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA
          NHO = 16 , INFO = NSUA-NUSC780
30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR )
NA NB ND NE NG NHO NH1 NI NL NM NO NO NS NSL NTO NT1
64 4096 15 2048 10 16 256 512 6 240 32 4 409 415 - 2 5
  ZSHLIM FTHRS0 FTHRS1 RZCUT0 RZCUT1 RZCUT2 DF1 DF2 NE1 0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000 4096
                                                                                     NE1 INVFLG
K12013
           K STREAM FOR H78X5
12 OCT 78 AT 1330 HR
                          512 NOV : 32
NK : 4 NTV :
M78X3 THROUGH CIDEAL AT +10. DB SNR
       TWIST = 119. ( 21.5 KT ) ; INFO = NSUA-NUSC78
16 APR 79 AT 1015 HR
STARTING TIME : 106 : 10 . 15 : 0 NO = 4
CENTER FREQUENCY : 204.800 CLOCK FREQUENCY : 0 819. 200
                                                                                    7080. BITS
                                           1180. SYMBOL5
            118. BURSTS
                                                       0.000000/ 0.000000 PE(SYM)
          0./ 0. SYMBOL ERRORS
  .MBOL ERRORS BY LOCATION :
                                                      ٥.
        0.
                 0. 0.
                    0.
         ₽.
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                                        0.
                                                                 ø.
        ٥.
                   0.
        0.
                    0.
                   L1 L2 L3 .
60.42 115.31 227.02
0.70 0.93 0.39
                                                                          TS1
                                                                TSO
                                                                                               TS3
       LO
                                                                -184.
      33.35
                                                               1461.
   FS0 FS1 FS2 FS3 F2 F2A F2B F3 F3A F3B
118.97 118.73 118.81 118.81 118.81 118.96 118.96 118.97 118.99 118.98 118.99
0.24 0.03 0.03 0.03 0.03 0.05 0.03 0.03 0.04 0.05
     0.24
 R2 R2A R2B R3 R3A R3B A2 A2A A2B A3 A3A A3B
1.000 0.902 1.000 1.000 0.900 1.000 0.010 0.005 0.006 0.001 0.006 0.006
0.000 0.010 0.000 0.000 0.008 0.000 0.001 0.001 0.001 0.001 0.001
  TP2A TP2B TP3A TP3B NZ2A NZ2B NZ3A NZ3B SNR2A SNR2B SNR3A SNR3B 167. -334. 107. -403. 2. 1. 2. 1. -3.9 -4.1 -1.1 -0.5 78. 43. 73. 69. 0. 0. 0. 0. 0. 0.2 0.2 0.1 0.1
                               53 Len( 225.) Lin(
14.1 2.71 2.21
0.0 0.12 0.11
                                                                           SE.) NDRV(
  INF2A INF2B INF3A INF3B
                                                                       2.29
   22.4 22.9 22.4 22.9
0.2 0.2 0.1 0.2
                                                                                          4.4
                                                                      0.16
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v w |

...EED : 21.5 ( 0.02) KTS

\* \* \*

OFFSET : 1.485126 ( 0.001114) HZ

\* \* \*

124: 11: 56 RECVR : 11 FEB 75A - BLOCK SUMMARY : 123: 10: 47 TO ( 25: 9) "78X3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA NHO = 16 , INFO = NSUA-NUSC780 30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR ) NA NB ND NE NG NHO NH1 NI NL NM NO NO NS NSL NTO NT1 NH 64 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 16 ZSHLIM FTHRS0 FTHRS1 R2CUT0 R2CUT1 R2CUT2 DF1 e.200 3.235 3.730 0.100 0.100 0.100 1.000 DF2 NE1 INVFLG 4096 1.000 K12013 K STREAM FOR M78X5 12 OCT 78 AT 1330 HR 512 NOV : NIV : 32 M7EXS THROUGH CIDEAL AT +5.0 DB SNR THIST = 119. ( 21.5 KT ) | INFO = NSUA-NUSC78 03 MAY 79 AT 1047 HR NO = STARTING TIME : 123 : 10 : 47 : 0 CLOCK FREQUENCY : 0 819. 200 CENTER FREQUENCY : 204.800 385. BURSTS 3850. SYMBOLS 23100. BITS 0./ 0. SYMBOL ERRORS 0.00000/ 0.000000 FE(5YM) MBOL ERRORS BY LOCATION : 0. 0. 0. ø. 0. 0. 0. 0. 0. 0. e. 0. 0. LØ LZ L3 TS2 L1 TSO TS1 TS3 23.24 50.77 96.54 190.44 -160. 0. 11.06 1.11 0.94 1.51 1411. FS0 FS1 FS2 FS3 F2 F2A F2B F3 F3A F3B 18.91 118.76 118.85 118.87 118.90 118.97 118.98 118.98 118.98 118.99 0.41 0.11 0.12 0.12 0.15 0.05 0.02 0.07 0.05 0.06 FS0 118.91 RZ RZA RZB R3 R3A R3B AZ AZA AZB A3 A3A A3B 1.000 0.312 1.000 1.000 0.303 1.000 0.044 0.004 0.004 0.008 0.004 0.004 0.003 0.018 0.000 0.000 0.015 0.000 0.080 0.003 0.003 0.003 0.003 NZZA NZZB NZ3A NZ3b SNRZA SNRZB SNR3A SNR3B TP2A TP2B TP3A TP3B 2. 1. Z. 1. 9. 0. -4.7 -4.8 -1.8 -1.7 0.3 0.2 0.2 0.2 150. -343. 119. -396. 0. 9. 84. 80. 75. 73. INF24 INF2E INF34 INF38 21.5 28.1 21.5 22.1 0.3 0.3 0.3 0.3 \$3 LENC 726.) 6.2 2.70 281.) NDEV( S3 LINC 2.28 0.0 0.12 0.16 2.4

\* \*

LPEED: 21.5 ( 0.02) KTS

\* \* \*

OFFSET: 1.485681 ( 0.001503) HZ

RECVR : 11 FEB 79A - BLOCK SUMMARY : 107: 7: 52 TO 108: 9: 1 ( 25: 9) 7BX3A - SPECIAL HIGH RATE VERSION FOR 178 NSUA NH0 = 16 , INFO = NSUA-NUSC780 30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR ) NA NB ND NE NG NHO NHI NI NE NM NO NG NS NSL NTO NTI NH 64 4086 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 16 DF2 NEI INVFLG DFi ZSHLIN FTHRSØ FTHRS1 R2CUTØ R2CUT1 R2CUT2 0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000 K12013 K STREAM FOR M78X5 12 OCT 78 AT 1330 HR NIV: 512 NOV: 32 M78A3 THROUGH CIDEAL AT @.@ DB SNR THIST = 118. ( 21.5 KT ) ; INFO = NSUA-NUSC78 17 APR 79 AT 0752 HR NQ = STARTING TIME : 197 : 7 : 52 : 0 CLOCK FREQUENCY: 0 819. 200 CENTER PREQUENCY : 204.800 3850. SYMBOLS 23100. BITS 0.000000/ 0.000000 PE(SYH) 9./ 0. SYMBOL ERRORS JYMBOL ERRORS BY LOCATION : 0. 0. **0. 6.** 0. 0. ø. 0. ø. ø. ø. 0. ٥. 9. 0. 0. .0. 9. ia ia Lo L4 TS0 12.25 33.65 63.87 126.10 1 73 -222. 1381. 6.45 3.05 1.70 1.73 FS0 FS1 FS2 FS3 F2 F2A F2B F3 F3H F32 118.84 118.74 118.90 118.92 118.83 118.97 118.98 118.98 118.98 118.99 0.58 0.17 0.12 0.12 0.21 0.01 0.04 0.08 0.04 0.06 RZB R3 R3A R3B 1.000 0.320 1.000 3.000 3.021 0.003 e.063 0.002 0.003 e.011 0.002 0.003 0.936 0.322 1.000 1.000 0.320 1.000 0.108 0.003 0.003 0.031 0.003 0.003 0.015 0.025 0.000 0.000 0.021 0.000 TP2A TF2B TP3A TP3B NZ2A NZ2B NZ3A NZ3B SNR2A SNR2B SNR3A SNR3B

SPEED: 21.5 1 0.02 / KTS OFFSET: 1.486259 ( 0.001552) HZ

0.7

0.0

S3 LONG

ê4. 75. 79. 79.

INTOA INFOB INFOA INFOB

12.8 20.2 13.8 29.2

0.3 0.4 0.3 0.4

2.71

0.12

\* \* \*

727.) LIN( 283.) NDBV(

0.15

2.28 -2.9

1.0

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RECVR : 11 FEB 79A - BLOCK SUMMARY : 110: 5: 4 TO 111: 0: 55 ( 15: 51)
   *8X3A - SPECIAL HIGH RATE VERSION FOR 178 NSUA
                     NHO = 16 , INFO = NSUA-NUSC780
30 OCT 78 AT 1109 MR ( RETYPED 05 JAN 78 AT 0757 HR )
NA NE ND NE NG NH0 NH1 N! NL NM NO NG NS NSL NT0 NT1 NW
54 4036 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 16
    ZSHLIM FTHRS0 FTHRS1 RZCUT0 RZCUT1 RZCUTZ DF1 DF2 NE1 INVFLG
0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000 4096 0
K12013
                     K STREAM FOR M78X5
12 OCT 78 AT 1330 HR
                                                                       Nov: 32
                              NIV :
                                                  512
M7BX5 THROUGH CIDEAL AT -5.0 DB SNR
              TWIST = 119. ( 21.5 KT ); INFO = NSUA-NUSC78
20 APR 79 AT 0904 HR
STARTING TIME : 110 : 5 : 4 : 0 NG = CENTER FREQUENCY : 204.800 CLOCK
                                                                                                   CLOCK FREQUENCY: 0 819. 200
          238, BURSTS 2380, SYMBOLS 14280, BITS
      0./ 0. SYMBOL ERRORS
                                                                                                                          e.000000/ 0.000000 FE(SYM)
SIMBOL ERRORS BY LOCATION :
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                e.
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                 e.
                                    0.
                                    Θ.
                C+ .
                                                           L2
                                                                              L3
                                                                                                                                                              TS2 TS3
                                                                                                                    TS0
              Le
                                                                                                                                           TS1
                                                         L2
31.39
                                    L1
    7.84
2.77
                                                                                61.46
                                  17.05
                                                                                                                                                                  ø.
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                                                                                                                                               1.
                                                                                                                       480.
                                  1,08 1,58 1,76
                                                                                                                                                                  5.
                                                                                                                                                                                    4.
                                                                                                                     1520.
  FS0 FS1 FS2 FS3 F2 F2A F2B F3 F3A F3B
118.95 118.81 118.94 118.96 118.86 118.97 118.98 118.98 118.99 119.00
0.36 0.19 0.11 0.10 0.19 0.04 0.05 0.06 0.05 0.03
  R2 R2A R2B R3 R3A R3B AZ A2A
                                                                                                                                    A2B A3
                                                                                                                                                                 ASA
                                                                                                    0.051 0.001 0.001 0.009 0.001 0.001
  0.954 0.931 1.000 1.000 0.925 1.000 0.051 0.001 0.001 0.005 0.001 0.001 0.005 0.001 0.001 0.005 0.001 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 
   TRZA TRZE TR3A TR3B NZ2A NZ2B NZ3A NZ3B 134. -371. 131. -383. 1. 1. 1. 1. 1. 85. 83. 85. 67. 0. 0. 0. 0.
                                                                                                                                    SNRZA SNRZB SNRJA SNRJB
  TRZA TRZE TRSA TRSE
                                                                                                                                -9.7 -9.7 -6.7 -6.7
0.5 0.5 0.3 0.4
                                                                  53 LONG 475.) LING 107.) NDBV( 32.)
  INF24 INF28 INF34 INF38
                                                                  -2.3
                                                                                                 Z.71
                                                                                                                                                  -3.4
2.4
 16.6 15.0 16.6 16.8
0.5 0.5 0.5 9.5
                                                                                                                                  2.28
                                                                  9.0
```

0.20

OFFSET : 1.486806 ( 0.001321) HZ

SPEEN: 21.5 ( 0.02) KTS

RECVR : 11 FEB 79A - BLOCK SUMMARY : 64: 10: 56 TO 65: 8: 6 ( 21: 10) \*\*\*\*ZEX3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA NH0 = 16 , INFO = NSUA-NUSC78030 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR )
NA NB ND NE NG NH0 NH1 NI NL NM NO NO NS NSL NT0 NT1
S4 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 16 ZSHLIM FTHRS0 FTHRS1 R2CUT0 R2CUT1 R2CUT2 DF1 DF2 NE1 0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000 4096 NET INVELS K12013 K STREAM FOR M78X5 12 OCT 78 AT 1330 HR NOV : 32 4 NIV: 512 M7EX3 THEOUGH CIDEAL AT -7.0 DB SNR TRIST = 119. ( 21.5 KT ) , [NFO = NSUA-NUSC76 05 MAR 75 AT 1056 HR STARTING TIME : 64 : 10 : 56 : 0 NO = 4 CLOCK FREQUENCY : 0 819. 200 CENTER FREQUENCY : 204.800 324. BURSTS 3240. SYMBOLS 19440. BITS 0./ 0. SYMBOL ERRORS 0.000000/ 0.000000 PE(SYM) JIMBOL ERRORS BY LOCATION : e, e, é, é, 0. 0. 0. 0. ٥. Θ. 0. 0. ٥. ø. 0. ø. ø. 0. ø. **G**... Li L2 L3 12.43 22.34 42.94 1.08 1.49 2.03 TS9 TS1 TS2 TS3 Le 6.61 12.43 617. 5. FS0 FS1 FS2 FS3 F2 F28 F3 F34 F38 118.92 118.83 118.97 118.98 118.85 118.97 118.98 118.99 118.99 119.00 0.31 0.24 0.10 0.10 0.23 0.07 0.05 0.05 0.05 R2 R2A R2B R3 R3A R3B A2 A2A A2B A3 A3A A3B 0.991 0.331 0.998 1.800 0.931 1.000 0.064-0.001 0.000 0.005 0.000 0.001 0.025 0.048 0.010 0.003 0.037 0.003 0.117 0.011 0.004 0.026 0.006 0.006 TP2A TP2B TP3A TP3B NZ2A NZ2B NZ3A NZ3B SNR2A SNR2B SNR3A SNR3B 147. -356. 130. -381. 1. 1. 1. 1. -11.2 -11.2 -8.3 -8.2 82. 86. 84, 86. 0. 0. 0. 0. 0. 0.6 0.5 0.5 0.5

INFZA INFZE INF3A INF3E 53 LONC 612.) L1NC 108.) NDBYC 15.9 15.2 15.9 15.2 -2.9 2.72 2.27 -3.7 0.6 0.5 0.6 0.5 0.0 0.14 0.13 0.3

INFOA INFOE INFOA INFOE

SPEED: 21.5 ( 0.02) KTS

OFFSET: 1.487075 ( 0.001311) HZ

65: 7: 55 RECVR : 11 FEB 79A - BLOCK SUMMARY : 64: 7: 56 TO "TEX3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA NH0 = 16 , INFO = NSUA-NUSC78030 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR )
NA NB ND NE NG NH0 NH1 NI NL NM NO NO NS NSL NT0 NT1
94 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 ZSHLIM FTHRS0 FTHRS1 RZCUT0 RZCUT1 RZCUTZ DF1 0.200 3.235 3.730 0.100 0.100 0.100 1.000 DFZ NET INVELO 1.000 4096 K12013 K STREAM FOR M78X5 12 OCT 78 AT 1330 HR NOV : 32 NIV : 512 M7BX3 THROUGH CIDEAL AT -9.0 DB SNR THIST = 119. ( 21.5 KT ); INFO = NSUA-NUSC78 05 MAR 79 AT 0756 HR STARTING TIME : 64 : 7 : 56 : 0 NO = 4 CENTER FREQUENCY : 204.800 CLOCK FREQUENCY : 0 819. 200 3680. SYMBOLS 368. BURSTS ZZ080. BITS e./ o. SYMBOL ERRORS 0.000000/ 0.000000 PE(SYM) . MBOL ERRORS BY LOGATION : o. o. 0. 0. 0. 0. ø, 0. 0. ø. 0. 0. 0. 0. 0. 0. ø. 0. ĒΘ La La ta L0 L1 L2 L3 TS0 TS1 5.39 8.72 15.22 29.24 914. 0. 1.33 0.87 1.34 1.70 1226. 5. FS0 FS1 FS2 FS3 F2 F2A F2B F3 F3A F3B 118.93 118.85 118.98 118.99 118.86 118.98 118.99 118.99 118.99 119.00 0.33 0.26 0.10 0.09 0.25 0.07 0.05 0.06 0.04 0.03 R2 R2A R2B R3 R3A R3B AZ A2A A2B A3 A3A A3B 0.982 0.897 0.979 1.000 0.937 0.999 0.063 0.000 0.001 0.003 0.000 0.001 0.041 0.106 0.094 0.003 0.043 0.008 0.124 0.021 0.031 0.025 0.011 0.006 TF2A TF2B TF3A TF3B NZ2A NZ2B NZ3A NZ3B SNR2A SNR2B SNR3A SNR3B 131. -372. 139. -375. 1. 1. 1. 1. -12.9 -12.9 -10.0 -10.0 88. 89. 86. 87. 0. 0. 0. 0. 0. 0.8 0.8 0.5 0.5 53 LON( 590.) LIN( 56.) NDEV( 48.)
-3.3 2.72 2.29 -3.8
0.0 0.14 BERNI AERNI BERNI OSRNI

13.4 13.6 13.4 13.6 0.7 0.7 9.7 9.7

..'EED : 21.5 ( 0.02) KTS

OFFSET : 1.487269 ( 0.001283) HZ

RECVR : 11 FEB 79A - BLOCK SUMMARY : 52: 8: 50 TO 53: 9: 58 BX3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA NH0 = 16 , INFO = NSUA-NUSC780 30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR ) NA NB ND NE NG NHO NH1 N1 NL NM NO NG NS NSL NTO NT1 64 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 ZSHLIM FTHRS0 FTHRS1 R2CUT0 R2CUT1 R2CUT2 DF1 0.200 3.235 3.730 0.100 0.100 0.100 1.000 DF1 DF2 NE1 INVFLG 1.000 4096 K12013 K STREAM FOR M78X5 12 OCT 78 AT 1330 HR 4 NIV: 512 NOV : 32 M7BX3 THROUGH IDEAL CHANNEL AT -10. DB SNR THIST = 119. ( 21.5 KT ); INFO = NSUA-NUSC78 21 FEB 79 AT 0850 HR : 52 : 8 : 50 : 0 NO = :Y : 204.800 CLOCK STARTING TIME CENTER FREQUENCY : CLOCK FREQUENCY : 0 819. 200 386. BURSTS 3860. SYMBOLS 23160. BITS 8./ 7. SYMBOL ERRORS 0.002073/ 0.001813 PE(SYM) SYMBOL ERRORS BY LOCATION : 0. 1. 0. 1. ❷. 1. ø. Э. 4 0. ο. 1. L2 L3 TS0 LØ. L1 TS1 TS2 -0. TS3 7.36 12.64 24.12 0.78 1.16 1.49 5.20 1058. Ĺ -0. 1.19 881. 5. 5. FS0 FS1 FS2 FS3 F2 F2A F2B F3 F3A F3B 118.91 118.82 118.99 118.99 118.83 118.95 118.95 118.99 119.00 0.32 0.30 0.08 0.07 0.30 0.05 0.07 0.07 0.04 0.02 R2 R2A R2B R3 R3A R3B A2 A2A A2B A3 A3A A3B 0.940 0.821 0.941 1.000 0.933 0.997 0.072-0.006-0.001 0.001 0.000 0.001 0.123 0.176 0.141 0.004 0.047 0.012 0.150 0.063 0.042 0.019 0.009 0.011 TP2A TF2B TF3A TF3B NZ2A NZ2B NZ3A NZ3B SNR2A SNR2B SNR3A SNR3B

NF3B \$3 L0N( 726.) L1N( 26.) NDBV( 12.7 -3.5 2.74 2.25 -3 0.7 0.0 0.15 0.15 A SPEED : 21.5 ( 0.01) KTS OFFSET: 1.487364 ( 0.000993) HZ

137. -373. 137. -374. 1. 1. 1. 1. -13.7 -13.7 -10.8 -10.8 90. 90. 84. 88. 0. 0. 0. 0. 0. 0.8 0.8 0.6 0.6

INFOA INFOS INFOA INFOB

12.5 12.7 12.5 12.7 0.7 0.7

50.)

2.25 -3.8 0.15 0.2

```
RECUR: 11 FEB 79A - BLOCK SUMMARY: 58: 13: 19 TO 59: 14: 20 ( 25: 1)
 78X3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA
         NHØ = 16 , INFO = NSUA-NUSC780
30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR )
NA NB ND NE NG NH0 NH1 NI NL NM NO NO NS NSL NT0 1
64 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2
                                                                NS NSL NTO HT1
  ZSHLIM FTHRS0 FTHRS1 RZCUT0 RZCUT1 RZCUT2 DF1 DF2 0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000
                                                                           NE1 INVFLG
K12013
         K STREAM FOR M78X5
12 OCT 78 AT 1330 HR
               NIV : 512 NOV :
                                           32
NIC .
        4
M7BX3 THROUGH CIDEAL AT -11.0 DE SNR
      TWIST = 119. ( 21.5 KT ); INFO = NSUA-NUSC78
27 FEB 79 AT 1319 HR
STARTING TIME : 58:13:19: 0 NO = 4
                                         CLOCK FREQUENCY : 0 819. 200
CENTER FREQUENCY : 204.800
     385. BURSTS /385 3850. SYMBOLS 23100. BITS
                                                 0.008312/ 0.007532 PE(SYM)
       32./ 29. SYMBOL ERRORS
SYMBOL ERRORS BY LOCATION :
               2.
                                              5. 0.
                                   ŝ.
       6.
                 6.
       З.
                                   3.
                                              7.
       3. i.
3. 6.
                           2.
                                                         0.
                                   LS 
                                                                                  T53
                                                      TSO
                                                                          TS2
      L0
            L1
                            LZ
                                                                                 ō.
                                                                          -4.
      4.73 6.31 10.49 19.62
0.94 0.69 0.98 1.36
                                                                <u>1</u>.
                                                     986, i.
836. 5.
    0.94
 FS0 FS1 FS2 FS3 F2 F28 F3 F3A F38 118.90 118.87 118.99 118.99 118.88 118.98 118.99 118.99 119.00 0.32 0.29 0.09 0.08 0.28 0.06 0.06 0.06 0.05 0.05
                                         0.28 0.06 0.06 0.06 0.05 0.05
                      R3 R3A R3B A2 A2A A2B A3 A3A A3B 000 0.925 0.956 0.041 0.002-0.006 0.002-0.001 0.000
  R2 R2A R2B
0.359 0.553 0.835 1.000 0.925 0.956 0.041 0.002-0.006 0.002-0.001 0.000 0.226 0.280 0.242 0.004 0.068 0.016 0.151 0.106 0.084 0.024 0.019 0.006
TP2A TP2B TP3A TP3B NZ2A NZ2B NZ3A NZ3B SNR2A SNR2B SNR3A SNR3B 123. -376. 125. -384. 1. 1. 1. 1. -14.6 -14.6 -11.8 -11.7 86. 85. 84. 84. 0. 0. 0. 0. 0. 1.1 1.0 0.7 0.7
                            53 LON( 748.) L1N( 18.) NDBV( 51.)
-3.6 2.73 2.29 -4.0
0.0 0.15 0.12 0.1
 INFZA INFZE INFJA INFJB
 11.5 11.7 11.5 11.7 -3.6
0.8 0.8 0.8 0.8 0.0
                                                    0.12
                                         0.15
                                                                           0.1
SPEED: 21.5 ( 0.02) KTS
                                       OFFSET : 1,487337 ( 0.001159) HZ
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\* \* :

RECVR : 11 FEB 79A - BLOCK SUMMARY : 57: 8: 22 TO 58: 9: 32 ( 25: 10) "78X3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA HH0 = 16 , INFO = NSUA-NUSC780 30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR ) NB ND NE NG NHO NH1 NI NL NM NO NG N5 N5L NTO NT1 NW 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 16 ZSHLIM FTHRS0 FTHRS1 R2CUT0 R2CUT1 R2CUT2 DF1 DF2 NE1 0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000 4096 NE1 INVFLG K12013 K STREAM FOR MYRXS 12 OCT 78 AT 1330 HR NIV: 512 Pmiss = .010471 NOV : M78x3 THROUGH IDEAL CHANNEL AT -12.0 DB SNR TWIST = 119. ( 21.5 KT ) ; INFO = NSUA-NUSC78 26 FEB 73 AT 9822 HR STARTING TIME : 57 : 8 : 22 : 0 NO = 4 CENTER FREQUENCY : 204.800 CLOCK FREQUENCY : 0 819. 200 378. BURSTS /382 3780. SYMBOLS 22680. BITS 0.019312/ 0.017725 PE(SYM) 73./ 67. SYMBOL ERRORS .YMBOL ERFORS BY LOCATION : 5 × 10 × 10 s. 6. s. 14. 6. 4. 7. 4. 13. 7. 12. 7. 5. S. 4. 7. 2. 12. Li L2 4.39 5.39 8 72 9.74 0.00 L3 TSØ TS1 8.73 16.13 TS2 TS3 ٥. 773. 0.**9**5 1.34 763. 4. FS1 FS2 FS3 FZ FZA R2 RZA RZB R3 R3A R3B AZ AZA AZB A3 ASA A3B 0.673 0.483 0.613 0.996 0.914 0.984 0.045-0.004 0.006 0.002-0.001-0.000 0.315 0.290 0.324 0.011 0.066 0.058 0.178 0.137 0.137 0.022 0.010 0.022 TF2A TF2B TF3A TF3B NZ2A NZ2B NZ3A NZ3B SNR2A SNR2B SNR3A SNR3B 135. -371. 138. -370. 2. 1. 1. 1. -15.3 -15.3 -12.5 -12.5 2. 1. 1. 1. -15.3 -15.3 -12.5 -12.5 1. 0. 0. 0. 1.3 1.2 0.7 0.7 89. 87. <u>8</u>7. **88**. INF24 INF28 INF34 INF3B \$3 LON( 844.) LIN( 10.6 19.8 19.7 10.8 -3.7 2.74 2. 8.) NDBV( 55.) 2 -3.9 10.5 19.8 19.7 19.2 -3.7 2.74 9.8 9.8 9.8 9.8 9.0 0.16 2.62 0.53 0.2 ⇒PEED : 21.5 ( 0.02) KTS OFFSET : 1.487334 ( 0.001155) HZ

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RECVR : 11 FEB 79A - BLOCK SUMMARY : 60: 10: 15 TO 61: 11: 11
  478X3A - SPECIAL HIGH RATE VERSION FOR '78 HSUA
           NHO = 16 , INFO = NSUA-NUSC780
 30 CCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR )
   NA NB ND NE NG NHO NH1 NI NL NM NO NO NS NSL NTO NT1 NW
64 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 16
   ZSHLIM FTHRS0 FTHRS1 RZCUT0 RZCUT1 RZCUT2
                                                       DF1
                                                               DF2
    9.200 3.235 3.730
                                                                       NE1 INVFLG
                           0.100 0.100 0.100 1.900
                                                              1.000 4096
 K12013
          K STREAM FOR MTBXS
                                                       Prior = . 375
 12 OCT 78 AT 1330 HR
               NIV ;
                       512
                               NOV :
                                          32
 M78X3 THROUGH CIDEAL AT -13.0 DB SNR
       THIST = 119. ( 21.5 KT ); INFO = NSUA-NUSC78
 91 MAR 79 AT 1019 HR
 STARTING TIME : 60 : 10 : 19 : 0
                                            NO =
 CENTER FREQUENCY : 204.800
                                             CLOCK FREQUENCY : 0 819, 200
            358. BURSTS /387
                                  3580. SYMBOLS
                                                                       21480. BITS
      245./ 224. SYMBOL ERRORS
                                                    0.068436/ 0.062570 FE(SYH)
  MEDL ERRORS BY LOCATION :
      22.
                       22. 25.
              27.
                                          3E.
                                                    12.
                                                              19.
                                                                        16.
      28.
                38.
      19.
                26.
                       18.
                               19. 28.
                                                    13.
                                                             19.
                                                                        15.
      27.
                40.
      Le
                L1
                          L2
                                    L3
                                                    T50
                4.67 7.38 13.22
0.56 0.85 1.36
                                                             TSI
                                                                     TS2
      4.00
                                                                              TSS
               4.67
                                                     441.
                                                              ø.
     0.53
                                                                               -0.
                                                          5.
                                                   777.
                                                                        5.
                                                                                6.
  FS0 FS1 FS2 FS3 F2 F2A F2B F3 F3A F3B 118.86 118.85 118.99 119.00 118.85 118.98 118.99 119.00 118.99 119.00
  0.33 0.31 0.05
                            0.08
                                      0.30 0.08 0.08 0.07 0.05 0.04
   R2 R2A R2B R3 R3A R3B
R2 R2A R2B R3 R3A R3B A2 A2A A2B A3 A3A A3B 0.486 0.307 0.390 0.985 0.845 0.947 0.042 0.007-0.001 0.000-0.002-0.001 0.327 0.260 0.321 0.078 0.158 0.125 0.196 0.178 0.139 0.026 0.037 0.037
 TPZA TFZE TP3A TP3B
                          NZZA NZZB NZ3A NZ3B SNRZA SNRZB SNR3A SNR3B
2. 2. 2. 1. -16.0 -16.1 -13.4 -13.4
8. 8. 8. 7. 1.4 1.3 1.0 0.9
 121. -374. 129. -365. 2.
59. 131. 98. 130. 8.
INFOA INFOB INFOA INFOB
                         S9 LON( 944.) L1N( -3.8 2.74
  9.7 3.9 9.9 9.8
6.0 3.0 6.0 8.9
                                                            24.) NDBV( 59.)
                                          2.74
                                                         2.87
                                                                     -4.0
9.1
                          ο..
                                                       0.64
                                           0.16
J∂EED :
         21.5 (
                   0.02) KTS
                                            OFFSET: 1.487409 ( 0.001083) HZ
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RECVR : 11 FEB 79A - BLOCK SUMMARY : 61: 12: 26 TO 62: 13: 25 ( 24: 58)
M78X3A - SPECIAL HIGH RATE VERSION FOR 178 NSUA
                       NH0 = 16 , INFO = NSUA-NUSC789
39 CCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR )
NA NB ND NË NG NHO NH1 NI NL NM NO NO NS NSL NTO NT1 NW
64 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 16
     ZSHLIM FTHRS0 FTHRS1 RZCUT0 RZCUT1 RZCUTZ DF1. DF2
0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000
                                                                                                                                                                      NE1 INVFLG
                                                                                                                                                                       4096
K12013
                       K STREAM FOR M78X5
                                                                                                                               Pmas = .40838
12 OCT 78 AT 1330 HR
                                                                                                32
                                                                          NOV :
                     4
                                 NIV :
                                                      512
M78X3 THROUGH CIDEAL AT -14.0 DB SNR
               THIST = 119. ( 21.5 KT ) ; INFO = NSUA-NUSC78
G2 HAR 79 AT 1226 HR
STARTING TIME : 61 : 12 : 26 : 0 NO = 4
CENTER FREQUENCY : 204.800 CLOCK FR
                                                                                                           CLOCK FREQUENCY: 0 819. 200
                          226 BURSTS /362 2260. SYMBOLS
                                                                                                                                                           13560. BITS
                                                                                                                                0.165487/ 0.125664 PE(SYM)
                                        284. SYMBOL ERFORS
               374.7
    .MBOL ERRORS BY LOCATION :
                                                                                                                                                      28.
                                                                                  42. 53.
                                                                                                                               26.
                                                                                                                                                                             27.
               44. 43.
                                     45.
               26.
                                                      24. 36. 38.
                                                                                                                          21.
                                                                                                                                                      27
                                                                                                                                                                             23.
                                    24.
                32.
               23.
                                      41.
                                                                                                                                                    TS1
                                                                                      L3
                                                                                                                                                                        T52
                                                                                                                                                                                           TS3
                                                                                                                             TSØ
                                                             LZ
                                    L1
               LØ
                                       4.30 6.47 19.81
                                                                                                                                                                        -0.
                                                                                                                                                                                          -0.
                                                                                                                                                     0.
                                                                                                                                190.
               3.84
                                                                 ø.67 1.40
                                                                                                                                715.
                                                                                                                                                         4.
                                                                                                                                                                             5.
                                                                                                                                                                                              6.
                                      0.42
           0.40
     FS0 FS1 FS2 FS3 FZ FZA FZB F3 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 118.99 
  RZ RZA RZB R3 R3A R3B A2 A2A A2B A3 A3A A3B
0.293 0.203 0.241 0.925 0.723 0.810 0.018 0.014-0.001 0.003-0.003 0.001
0.282 0.206 0.256 0.181 0.242 0.279 0.223 0.186 0.202 0.058 0.082 0.082
     TPZA TPZB TP3A TP3B NZ2A NZ2B NZ3A NZ3B SNR2A SNR3B SNR3A SNR3B 135. -380. 126. -381. 4. 2. 2. 1. -16.6 -16.7 -14.3 -14.3 157. 124. 117. 131. 13. 10. 10. 7. 1.4 1.5 1.0 1.1
    157. 124. 117. 131.
                                                                        53
                                                                                             LONG 1399.1 LING 111.) HDBVG 76.)
   INF24 INF28 INF34 INF38
                                                                                                                                             3.01 -4.0
9.60 ' 0.1
       8.6 9.0 9.0 9.1 -3.8
1.0 9.9 0.9 0.0
                                                                                                          2.75
                                                                                                          0.18
```

./EED : 21.5 ( 0.02) KTS

\* \* \*

OFFSET : 1.487345 ( 0.001060) HZ

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RECVR : 11 FEB 79A - BLOCK SUMMARY : 108: 7: 49 TO 109: 6: 30 ( 22: 41)
   'BX3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA
            NdO = 16 , INFO = NSUA-NUSC780
  30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR )
    NA NB ND NE NG NHO NH1 NI NL NM NO NO NS NSL NTO NT1
64 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5
                                                                  NS NSL NTO NT1
    25HLIM FTHRS0 FTHRS1 R2CUT0 R2CUT1 R2CUT2 DF1
                                                                    DF2
                                                                             NE1
                     3.730 0.100 0.100
     0.200 3.235
                                                 0.100
                                                           1.000 1.000
          K STREAM FOR M78X5
  12 OCT 78 AT 1390 HR
           4
                 NIV :
                          512
                                    NOV :
  M7BX3 THROUGH CELTHRA CHANNEL AT +10. DB SNR
        TWIST = 119. ( 21.5 KT ) ; INFO = NSUA-NUSC78
 18 APR 79 AT 0749HR
 STARTING TIME : 108 : 7 : 49 : 0
CENTER FREQUENCY : 204.800
                                               NG = 4
CLOCK FREQUENCY: 0 819, 200
           349. BURSTS
                                          3490. SYMBOLS
                                                                          20940. BITS
        0.7 0. SYMBOL ERRORS
                                                   0.000000/ 0.000000 PE(5YM)
 SYMBOL ERRORS BY LOCATION :
                                                           0.
        0. 0.
                                                                     0.
         æ,
                   ⅌.
         ø.
                   0.
                             0.
         ¢.
                   Α.
                             LŹ
                                     Lä
       L@
                 L1
                                                                   T51
                                                                           TSE
                                                                                     T53
              46.57 84.77
                                                                           -1.
      21.78
                                       167.98
                                                                                    4
                            0.75 0.73
                                                        -1193.
     10.23
                   0.62
                                                         586.
                                                                              1.
                                                                                       1.
   FS0 FS1 FS2 FS3 FZ FZA FZB F3 F3A F3B
115.00 118.60 119.00 119.00 118.60 118.97 118.37 118.98 118.98
0.31 0.11 0.01 0.01 0.11 0.04 0.04 0.06 0.00 0.01
  RZ RZA RZB R3 R3A R3B AZ AZA AZB A3 A3A A3B
0.979 0.978 0.933 0.998 0.954 0.937 0.173-0.002-0.001-0.000-0.001-0.000
0.0Z1 0.017 0.0Z0 0.004 0.012 0.0Z7 0.002 0.000 9.000 0.000 0.000
   TP2A TP2B TP3A TP3B NZ2A NZ2B NZ3A NZ3B SNR2A SNR2B SNR3A SNR3B 170. -320. 166. -346. 4. 3. 4. 3. -4.3 -4.3 -1.4 -1.2 40. 22. 41. 53. 6. 6. 0. 0. 0. 0.2 2.1 0.1 0.2
                               53 LON( 649.) LIN( 354.) NDEV( 14.1 2.71 2.26 2
  INFZA INFZE INF3A INF3B
  20.2 20.2 20.2 20.2
40.1 0.2 0.1 0.1
                                                                                2.5
                                                           0.17
                                                                               5.2
*SPEED : 21.5 ( 0.00) KTS
                                                 OFFSET: 1.487500 ( 0.000167) HZ
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RECVR : 11 FEB 79A - BLOCK SUMMARY : 124: 10: 50 TO
                                                   125: 12: 0
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"78X3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA NH0 = 16 , INFO = NSUA-NJSC780

30 CCT 78 AT 1105 HR ( RETYPED 05 JAN 78 AT 0757 HR )

NA NE ND NE NG NHO NH1 NI NL NN NO NO NS NSL NTO NT1 64 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 NU 16

ZSHLIM FTHRS0 FTHRS1 R2CUT0 R2CUT1 R2CUT2 DF1 DF2 NE1 0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000 4096 NE1 INVFLG

K12013

K STREAM FOR M7BX5

12 OCT 78 AT 1330 HR

4 NIV: 512 NOV :

M7BX3 THROUGH CELTHRA AT +5.0 DE SNR

THIST = 119. ( 21.5 KT ) ; INFO = NSUA-NUSC78

04 MAY 79 AT 1050 HR

STARTING TIME : 124 : 10 : 50 : 0 NQ =

CENTER FREQUENCY : 204.800 CLOCK FREQUENCY : 0 819. 200

389. BURSTS 3890. SYMBOLS 23340. BITS 0. SYMBOL ERRORS 0.000000/ 0.000000 PE(SYM) \_YMBOL ERRORS BY LOCATION : ο. 0. ø. 0. Ø. Ø. ø. 0. e. ø. €. e. ø. ø. 0. 0. ø., ø.

LO L1 LZ L3 TSØ TS3 TS1 TS2 16.03 38.96 71.22 140.84 -1203. 1. -1. 1. 8.28 2.43 1.19 1.13 569. 1 .

FS1 FS2 FSA F2 F2A F2B F3 FSA FRR 118.88 118.59 119.00 119.00 118.59 118.37 118.97 118.98 118.98 118.99 0.44 0.10 0.00 0.00 0.10 0.03 0.05 0.03 0.04 0.04

270 R2B R3 A2 A2A A2B A3 A3A A3B 0.169-0.002-0.001-0.000-0.001-0.000 R3A R3B 0.965 0.972 0.921 0.992 0.950 0.937 0.029 0.025 0.030 0.016 0.014 0.030 0.056 0.000 0.000 0.000 0.000 0.000

NZZA NZZB NZSA NZSB TP2A TF2B TP3A TP3B SNRZA SNRZB SNRZA SNRZB 158. -327. 152. -357. 53. 97. 53. 58. 1: 3: 4: 3: 6: 6: 6: 8: -5.0 -5.0 -2.1 -2.0 0. 0.2 6.2 9.2 6.2

INFEA INFES INFEA INFES 33 LONG 712.) LIN( 390.) NDBV( 50.) 19.7 19.5 19.6 19.6 6.2 2.79 2.27 -1.3 6.8 6.3 8.2 6.3 9.0 0.12 0.14

JPEED: 21.5 ( 0.00) KTS

OFFSET: 1.487500 ( 0.000000) HZ

( 25: 10)

RECVR : 11 FEB 79A - BLOCK SUMMARY : 109: 9: 17 TO 109: 20: 25 ( 11: 8) BX3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA NHO = 16 , INFO = NEUA-NUSC780 30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR ) NA NB ND NE NG NHO NHI NI NL NM NO NO NS NSL NTO NTI 34 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 ZSHLIM FTHRS0 FTHRS1 R2CUT0 R2CUT1 R2CUTZ DF1 DF2 NE1 INVFLG 0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000 K12013 K STREAM FOR M78X5 12 OCT 78 AT 1330 HR 4 NIV: 512 NOV: 32 M7BAS THROUGH CELTHRA CHANNEL AT 0.0 DB SNR TWIST = 119. ( 21.5 KT ); INFO = NSUA-NUSC78 19 APR 79 AT 0917 HR STARTING TIME : 109 : 9 : 17 : 0 NQ = 4 CENTER FREQUENCY : 204.800 CLOCK FRE CLOCK FREQUENCY: 0 819, 200 166. BURSTS 1680. SYMBOLS 9960. BITS 0.000000/ 0.000000 PE(SYM) 0.7 0. SYMBOL ERRORS SYMBOL ERRORS BY LOCATION : ♥. ø. ø. 0. 0. e. 0.

0. 0. 0. 0. 0. Ø. ø. TSØ Lø TS1 L3 TS2 TSS L1 LZ 26.19 47.49 93.39 12.61 -880. 1. -1. 1. 5.02 1.18 1.47 1.55 1298. 2. FS1 FS2 FS3 F2 F2A F2B F3 FSA F3A 118.95 118.58 119.00 119.00 118.58 118.96 118.97 118.98 118.98 118.99 0.04 0.09 0.04 0.10 0.04 0.03 0.04 0.03 0.04 RZ RZP RZB R3 R3A R3B AZ AZA AZB A3 A3A A3B 0.954 0.944 0.907 0.974 0.938 0.934 0.182-0.002-0.001-0.000-0.000-0.000 0.049 0.002 0.001 0.000 0.001 0.001 0.036 0.038 0.034 0.026 0.024 0.031 NZZA NZZB NZ3A NZ3B SNRZA SNRZB SNR3A SNR3B 4. 3. 4. 3. -6.7 -6.7 -3.8 -3.8 TP2A TF2B TF3A TP3B 3. -6.7 -6.7 -3.8 -3.8 1. 9.4 9.4 9.3 0.3 144. -346. 138. -372. 60. 54. 58. 58. ٠. ٥. 340.) LIN( 133.) NDBV( \$3 Long e.7 -2.7 INFOA INFOB INFOA INFOB 2.71 2.29 16.3 18.0 18.2 18.1 0.15 ñ.o 0.3 0.4 0.3 0.4 0.13 1.3 OFFSET : 1.487439 ( 0.000454) HZ SPEED : 21.5 ( 0.00) KTS

\* \* \*

\* \* 1

RECVR : 11 FEB 79A - BLOCK SUMMARY : 28: 13: 35 TO 29: 16: 5 'EX3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA NHO = 16 , INFO = NSUA-NUSC780 30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR )
NA NB ND NE NG NHG NH1 NI NL NM NO NG NS NSL NTG NT1
64 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 2 5 16

DF1

NE1 INVFLG

K12013

K STREAM FOR MTRX5

12 0C1 78 AT 1330 HR

NIV : NOV : 512

M78X3 THROUGH CELTHRA CHANNEL AT -5.0 DB SNR TWIST = 119. ( 21.5 KT ) , INFO = NSUA-NUSC78

28 JAN 78 AT 1335 HR

STAFFING TIME : 28 : 13 : 35 : 0 NQ = 4

CENTER FREQUENCY : 204,800 CLOCK FREQUENCY: 0 819. 200

ZSHLIM FTHRS0 FTHRS1 R2CUT0 R2CUT1 R2CUT2 DF1 DF2 NE1 0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000 4096

410. BURSTS 4100. SYMBOLS 24600. BITS G. SYMBOL ERRORS 0.000000/ 0.000000 PE(SYM)

SYMBOL ERRORS BY LOCATION : e. 0. 0. 0. 0. 0. 0. ¢٠. 0. 0. ∅. 0. Ø. 0. 0. G. 0. 0.

Le L1 L2 L3 TS0 T51 TSZ T53 7.15 13.11 45.32 1.76 23.30 -373. -1. 1. 2. 2.35 1.03 1.33 1516. 2. 2.

FSO FS1 FS2 FS3 F2 FZA F2B F3

R2A R2B R3 RGA RGB A2 A2A A2B A3 A3A A3B 0.167-0.001-0.001 0.001-0.000-0.000 0.887 0.857 0.875 0.947 0.901 0.911 0.055 6.058 9.049 0.037 0.044 0.040 0.057 0.003 0.006 0.011 0.002 0.002

NZZA NZZB NZ3A NZ3B SNRZA SNRZB SNR3A SNR3B 4. 4. 4. 4. -9.9 -8.9 -6.9 -6.9 1. 1. 0. 1. 0.5 0.5 0.4 0.4 TPEA TPEB TPEA TPEB 139. -359. 134. -371. 59. 96. 57. 56,

LON( 750.) LIN( 237.) NDBV( 52.)
2.73 2.27 ---83 IMF2A INF2B INF3A INF3B 15.4 15.2 15.5 15.4 -2.3 v.5 0.6 0.5 0.5 0.6

2.27 -3.5 0.16 0.5

SPEED: 21.5 ( 0.01) KTS OFFSET : 1.487329 ( 0.000887) HZ

```
55: 0: 28 ( 37: 37)
RECUR : 11 FEB 79A - BLOCK SUMMARY :
                                     53: 10: 51 TO
M78X3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA
        NHO = 16 , INFO = NSUA-NUSC780
30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 6757 HR )
NA NE ND NE NG NHO NHI NI NL' NH NO NO NS NSL NTO NTI
64 4086 15 2048 10 16 256 512 6 240 32 4 409 415 2 5
                                                                              NH
                                                                              16
                                                    DF4
                                                                   NE4 INVELG
  ZSHLIM FTHRSO FTHRS1 RZCUTO RZCUT1 RZCUTZ
                                                             DF2
  0.200 3.235 3.730 0.100 0.100 0.100 1.000
                                                           1.000
K12013
        K STREAM FOR M7BX5
12 OCT 78 AT 1330 HR
                               NOV :
              NIV : 512
        4
M7EX3 THROUGH CELTHRA CHANNEL AT -7.0 DB SNR
      TWIST = 119. ( 21.5 KT ) , IMFO = NSUA-NUSC78
      ( REWRITTEN VERSION OF POSSIBLY DEFECTIVE 023:08 TAPE )
22 FEB 79 AT 1051 HR
STARTING TIME : 53 : 10 : 51 : 0
                                           NQ =
                                           CLOCK FREQUENCY : 0 819. 200
CENTER FREQUENCY : 204.800
                                     5780. SYMBOLS
                                                                     34680. BITS
           578. BURSTS
                                                    0.000173/ 0.000173 PE(SYM)
                  1. SYMBOL ERRORS
 (MBOL ERRORS BY LOCATION :
                                                    0.
                                                             0.
                                                                      0.
       0.
                0.
                                  0.
                                           1.
       0.
                0.
       ø.
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                                  ₩.
                                           1.
                                                    ٥.
                                                             0.
                G .
                0.
                                                                   TSZ
                                   31 .95
                                                                            TS3
                         L2
                                                   TS0
                                                           T51
      Le
                L1
                                                  -151.
      5.86
                9.63
                         16.66
                                   1.57
                                                  1544.
                0.94
                          1.25
      1.52
  FS9 FS1 FS2 F53 F2 F28 F3 F3A F3B 118.82 118.63 118.98 118.98 118.65 118.97 118.97 118.98 118.98 118.98
    2.35 0.23 0.08 0.05 0.23 0.07 0.05 0.05 0.03 0.05
                                             A2 A2A A2B
                    R3 R3A R3B
                                                               Δ3
   RZ RZA RZB
 0.819 0.778 0.827 0.926 0.872 0.897
                                          0.153-0.001-0.001 0.001 0.000 0.000
```

NZZA NZZB NZZA NZZB

(NF2A INF2B INF3A INF3B S3 LON( 1077.) L1N( 268.) NDBV( 75.) 13.9 13.8 14.1 13.9 -3.9 2.72 2.30 -3.7

1.

0.0

5. 4. 4. 4.

1.

0.14

1.

0.085 0.087 0.062 0.041 0.050 0.045

58.

TP2A TP2B TP3A TP3B

60.

9.€

£2.

136. -359. 136. -373.

57.

Ø.6

/EED: 21.5 ( 0.01) KTS

0.115 0.018 0.003 0.012 0.007 0.003

OFFSET : 1.487279 ( 0.001015) HZ

0.16

SNR2A SNR2B SNR9A SNR3B

-11.4 -11.3 -8.4 -8.4

0.6 0.6 0.4 0.5

0.3

```
RECVR : 11 FEB 79A - BLOCK SUMMARY :
                                    50: 8: 33 TO
                                                    51: 22: 18 ( 37: 45)
M7BX3A - SPECIAL HIGH RATE VERSION FOR 178 NSUA
        NHO = 16 , INFO = NSUA-NUSC780
30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR )
      NB ND NE NG NHO NHI NI NL' NM NO NO NS NSL NTO NTI NH
 64 4096 15 2048 10 16 256 512 6 240 32 4 409 415 . 2
                                                                    5 16
 28HL1M FTHRS0 FTHRS1 R2CUT0 R2CUT1 R2CUT2 DF1 DF2 NE1 0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000 4096
                                                               NEI INVELG
                                                                         0
K12013
        K STREAM FOR MTUX5
12 OCT 78 AT 1330 HR
NK: 4
             NIV :
                     512
                            NOV :
M78X3 THROUGH CELTHRA CHANNEL AT -8.0 DB
     THIST = 119. ( 21.5 KT ) , INFO = NSUA-NUSC78
19 FER 73 AT 0833 HR
STARTING TIME : 50 : 8 : 33 : 0
                                      NG =
                                        CLOCK FREQUENCY : 0 819, 200
CENTER FREQUENCY :
                  204.500
          583. BURSTS
                                  5830. SYMBOLS
                                                              34980. BITS
       2.7 2. SYMBOL ERRORS
                                              0.000343/ 0.000343 PE(SYH)
 HBOL ERRORS BY LOCATION :
             0.
      1.
                               0.
                                       Ø.
                                                0.
                                                        0.
                                                              1.
              0.
      O.
      1.
              0.
                       0.
                               ø.
                                       0.
                                                ø.
                                                        9
      0.
              ø.
     Le
              L1
                       L2
                                L3
                                               TSØ
                                                      TSI
                                                              TS2
                                                                     TS3
             8.13
                              26.43
1.49
     5.38
                       13.85
                                               -28.
                                                      0.
                                                              -0.
                                                                      1.
     1.33
              0.78
                       1.12
                                              1483.
                                                        2.
                                                                2.
                FS2 FS3
   FS0
        ES1
                                    F2
                                          FZA FZB F3
                                                             FBA
 118.84 118.64 118.98 118.98 118.65 118.97 118.97 118.98 118.98 118.99
   0.32 0.24
                0.08
                        0.08
                                  0.24 0.05 0.05 0.06 0.08 0.01
                  R3 R3A R3B
   R2 RZA
            R2B
                                         ASA SA
                                                   AZB
                                                          A3 A3A A3B
0.748 0.697 0.762 0.918 0.858 0.889
0.111 0.105 0.075 0.042 0.057 0.046
                                       0.153-0.000-0.001 0.000-0.000 0.001
                                       0.118 0.018 0.009 0.016 0.003 0.008
 TP2A TP2B TP3A TP3B
                         NZZA NZZB NZJA NZJB
                                                   SNRZA SNRZB SNRZA SNRZB
                        5. 4. 4. 4.
1. 1. 1. 1. 1.
 143. -359. 187. -388.
                                                   -12.2 -12.2 -9.3 -9.2
0.7 0.7 0.5 0.5
       61.
             58. 53.
                                                               0.5 0.5
 WESA INFOR INFOR INFOR
                         33
                                 LON( 1068.: LIN( 228.) NDBV(
                                                                    75.)
 13.1 13.0 13.3 13.2
0.7 0.7 0.6 0.7
                         -3.1
0.0
                                2.73
0.15
                                                   2.28 -3.8
                                                   0.15
                                                                 0.3
```

\* \* -

21.5 ( 0.02) KTS

\* \* \*

OFFSET : 1.487294 ( 0.001059) HZ

```
20: 17: 17 ( 25: 16)
                                       19: 16: 1 TO
RECVR : 05 FEB 79A - BLOCK SUMMARY :
M78X3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA
         NHO = 16 , INFO = NSUA-NUSC780
30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR )
 NA NB ND NE NG NHO NH1 NI NE NM NO NO NS NSL NTO NT1
64 4086 15 2048 10 16 256 512 6 240 32 4 405 415 2 5
                                                        4 409 415 2 5 16
 ZSHLIM FTHRS0 FTHRS1 RZCUT0 RZCUT1 RZCUT2 DF1 DF2 0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000
                                                              DF2 NE1 INVFLG
                                                                      4096
K12013
         K STREAM FOR M7BX5
12 OCT 78 AT 1330 HR
                               NOV :
              NIV: 512
M78X3 THROUGH CELTHRA CHANNEL AT -8.5 DB
      TRIST = 119. ( 21.5 KT ) , INFO = NSUA-NUSC78
19 JAN 79 AT 1501 HR
STARTING TIME : 19 : 16 : 1 : 0
                                            NQ =
                                                                  0 819. 200
                                             CLOCK FREQUENCY :
CENTER FREQUENCY : 204.800
                                3880. SYMBOLS 23280. BITS
           388. BURSTS
                                              0.001289/ 0.001031 PE(SYM)
                  4. SYMBOL ERRORS
 MBOL ERRORS BY LOCATION :
                                                                1.
                                                      Ø.
                                    1.
                                             2.
               0. 0.
                 1 -
       0.
                                             2.
                                                      0.
                                                                1.
                                    0.
                          0.
       ø.
                 ø.
       ø.
                 1.
                                                                     TS2
                                                                               TS3
                                                    TS0
51.
                                                              TS1
                                     L3
                           L2
                1.1
      LO
                      12.54 23.87
                                                               1.
               7.39
      5.08
                                                    1461.
                                     1.50
                         1.98
                 0.75
      1.15
  F50 FS1 FS2 FS3 F2 F28 F3 F3A F3B 113.83 118.67 118.98 118.99 118.67 118.97 118.97 118.98 118.98 118.99 0.32 0.26 0.08 0.07 0.26 0.05 0.07 0.06 0.04 0.05
                                             AZ AZA AZB
 R2 R2A R2B R3 R3A R3B
0.699 0.641 0.716 0.913 0.841 0.878
                                                                   A3
                                                                        ASA
                                            0.139-0.001-0.001 0.002-0.000-0.000
                                         0.126 0.031 0.015 0.015 0.003 0.003
 0.132 0.114 0.092 0.045 0.061 0.047
                             NZZA NZZB NZGA NZGB
  TP2A TP2B TP3A TP3B NZ2A NZ2B NZ3A NZ3A 141. -363. 137. -372. 5. 4. 5. 4. 1. 1.
                                                           SNR2A SNR2B SNR3A SNR3B
                                                           -12.5 -12.6 -5.7 -5.6
0.8 0.8 0.5 0.5
                                 2.
```

0.14

-3.2

0.0

£1. 58. **59.** 

0.7 9.7

INFOA INFOB INFOA INFOB

12.6 13.6 12.9 12.8

'EED : 21.5 ( 0.01) KTS

0.7

OFFSET : 1.487300 ( 0.000939) HZ

0.3

53 LON( 729.) LIN( 134.) NDEV( 50.) -3.2 2.73 2.27 -3.8

0.14

RECVR : 11 FEB 79A - BLOCK SUMMARY : 18: 9: 35 TO ( 36: 37)

'BX34 - SPECIAL HIGH RATE VERSION FOR '78 NSUA NH0 = 16 , INFO = NSUA-NUSC780

30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR )

NA NB ND NE NG NHO NHI NI NL NM NO NG NS NSL 34 4056 15 2048 10 16 259 512 6 240 32 4 409 415

ZSHLIM FTHRS0 FTHRS1 RZCUT0 RZCUT1 RZCUT2 DF1 0.200 3.235 3.730 0.100 9.100 0.100 1.000 DF2 NE1 INVFLG 1.000 4096

K12013

K STPEAM FOR M7BX5

12 OCT 78 AT 1330 HR

4 NIV : 512 Nev :

M78X3 THROUGH CELTHRA CHANNEL AT -9.0 DB THIST = 119, ( 21.5 KT ) , LHFO = NSUA-NUSC78

18 JAN 79 AT 0939 HR ( REPLACES BAD TAPE OF 010:13 )

STARTING TIME : 18 : 3 : 39 : 0 CENTER FREQUENCY : 204.800 NQ = 4

CLOCK FREQUENCY :

	5	iss. Bu	RSTS		5	550. S	MBOLS	85.7%		33900	. BITS
	24./		12. SY	MBOL ERROR	रेड		0.	004248/	0.002	:124 P	E(SYM)
SYMBOL	ERROR	S BY L	OCATIO	Ň :							Artin Maria. Ma
	4.	ø.	V - 5 / 10 / 10 / 10 / 10 / 10 / 10 / 10 /	0.	0.	6.	1.			<b>q</b> a	
		€.						·		• •	
	Э,			9.	0.	2.	1.	8	r.	1.	
	e.	2.									
1	_0	L1		L2	L3		TSØ	T51	. 7	'S2	TSS
4	4.98	6.	90	L2 11.54 1.08	21.74	No.	370	. 1	4	-0.	a.
1	1.05	0.	73	1.08	1,41		1324	. 3	•	z.	2.
FSC	)	FS1	F52	FS3	2. 60	F2 F	2A F	2B F3	F	3A	Far
118.8	31 11	8.67	118.98	118.98	118	.69 11	8.97 114	3.97 118	.98 11	8.98	118.99
0.3	31	0.27	0.08	FS3 118.98 0.08	é	.27	0.06 (	0.06	.05	0.05	0.07
R2	R2A	R2B	Ŕŝ	R3A R	ЭВ	A	2 A2A	AZB	43	A3A	ASR
0.651	0.586	0.664	0.904	0.829 0.A	73	0.1	34-0 GAC	1-0 007	a aaa_	a aca	0 000
0.135	0.124	0.098	0.046	0.066 0.0	54	0.1	32 0.032	0.018	0.015	0.005	0.007
TPZA	TPZB	TPSA	TP32	NZ2A	NZ2B	NZSA	NZ3B	SNRZA	SNR2B	SNR3A	SNR38
138.	-354.	139,	-371.	5.	4.	4.	4.	-13.0	-13.0	-10.1	-10.1
68.	51.	57.	58.	2.	1.	1.	1.	9.8	0.8	0.5	0.5
INF2A	INFER	INF3A	INFOR	S3 - 3 3	LONG	1041	.) L18	IC 130	.) ND	BV(	78.)
12.2	12.1	12.5	12.4	-3.3		2.74		2.29	a de la serie La companya	-3.7	
0.7	0.7	0.7	0.7	-3.3 0.0		0.15		0.15		9,3	3
SPEED :	21	.5 (	0.02)	KTS		OF	FSET :	1.48728	3 ( 0	.00104	(4.) HZ

\* \* \*

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RECVR : 06 FEB 79A - BLOCK SUMMARY : 11: 9: 27 TO 12: 18: 13 ( 33: 46)
"78X3A - SPECIAL HIGH RATE VERSION FOR 178 NSUA
          NHO = 16 , INFO = NSUA-NUSC780
30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR )
NA NB ND NE NG NH0 NH1 NI NL NM NO NO NS NSL NT0 NT1
G4 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5
  ZSHLIM FTHRS0 FTHRS1 R2CUT0 R2CUT1 R2CUT2 DF1 DF2 NE1 0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000 4096
                                                                                NE1 INVFLG
K12013
          > STREAM FOR M78X5
12 OCT 78 AT 1330 HR
                NIV :
                          512
                                    NOV :
M7BX3 THROUGH CELTHRA CHANNEL AT -10.0 DB
       TNIST = 119. ( 21.5 \text{ KT} ) , INFO = NSUA-NUSC78
11 JAN 79 AT 9927 HR
STARTING TIME : 11 : 9 : 27 : 0 NG = CENTER FREQUENCY : 204.800 CLOCK
                                                  CLOCK FREQUENCY :
                                                                            0 819. 200
            512. BURSTS
                                     5120. SYMBOLS
                                                               30720. BITS
        64.7
                    40. SYMBOL ERRORS
                                                   0.012500/ 0.007812 PE(SYM)
                                                                            distribute
 MBOL ERRORS BY LOCATION :
                7.
                                                  8.
                           6.
                                       1.
        2.
                 13.
        3.
                 2.
                             5.
                                       2.
                                                  8.
                                                             2.
                                                                        З.
                 10.
      Lø
                  L1
                              L2
                                         L3
                                                           TS0
                                                                     TS1
                                                                               T52
                                                                                        T53
      4.64
                             9.64
                                        17.89
1.37
                  5.86
                                                           467.
                                                                                           1.
      0.86
                              1.02
                  0.70
                                                                                 3.
                                                                                           3.
 FS0 FS1 FS2 FS3 F2 F2A F2B F3 F5A F3B
118.77 148.69 118.98 118.98 118.70 118.97 118.97 118.99 115.98 118.99
6.31 0.29 0.08 0.08 0.29 0.04 0.06 0.06 0.05 0.06
                                                AZ AZA AZB A3 A3A A3B
0.118-0.000-0.002-0.000-0.000 0.001
R2 R24 R2B R3 R34 R3B
0.520 0.456 0.537 0.832 0.782 0.839
0.167 0.148 3.130 0.052 0.087 0.062
                                                 0.152 0.068 0.041 0.015 0.012 0.009
 135. -367. 134. -372. 6. E 2
                                                                5NRZA SNRZB SNR3A SNR3B
                               6. 5. 5. 4.
2. 2. 1. 1.
                                                               -13.8 -13.8 -11.0 -10.9
0.9 0.9 0.6 0.6
        52. 59. 58.
                                53 LONG
-3.5
INFIA INFIB INFIA INFIB
                                                            L1N( 71.) NDBV(
2.31 -3.9
0.20 0.2
                                          LONG 1004.) LING
 11.2 11.2 11.7 11.6
0.8 9.6 0.8 0.8
                                                2.73
                                0.0
                                               9.15
 'EED : 21.5 ( 0.91) KTS
                                                  OFFSET: 1.487275 ( 0.001005) HZ
```

\* \* 3

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RECVR : 11 FEB 79A - BLOCK SUMMARY : 15: 7: 52 TO 15: 23: 42 ( 15: 50)
M7BX3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA
         NHO = 16 , INFO = NSUA-NUSC780
30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR )
NA NB ND NE NG NHO NH1 NI NL NM NO NO NS NSL NTO NT1 NH
64 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 16
                                                           DF2 NE1 INVFLG
  ZSHLIM FTHRSØ FTHRS1 RZCUTØ RZCUT1 RZCUT2
                                                      DF1
   0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000 4056
         K STREAM FOR M7BX5
12 OCT 78 AT 1330 HR
NK :
        4
              NIV :
                     512
                              NOV : 32
                                                     gaus "
M78X3 THROUGH CELTHRA CHANNEL AT -11.0 DB
      TWIST = 119. ( 21.5 KT ) , INFO = NSUA-NUSC78
15 JAN 79 AT 0752 HR
STARTING TIME : 15 : 7 : 52 : 0 NO =
CENTER FREQUENCY : 204.800
                                          CLOCK FREQUENCY: 0 819, 200
                                                     14640. BITS
                           2440. SYMBOLS
           244. BURSTS /246
      106.7
                63. SYMBOL ERRORS
                                                    0.043443/ 0.025820 PE(SYM)
 MBOL ERRORS BY LOCATION :
                             Ŝ.
           8.
     14.
                                          A.
                                                   13. 13. 12.
              18.
      6 :
      7.
               6.
                       0.
                                5.
                                         2.
                                                   7.
      E.
              16.
     LØ
              L1
                       LZ
                                  L3
                                                   TSØ
                                                           TS1
                                                                  TS2
                                                                           T53
              5.02
                         8.01 14.61
     4.21
                                                            0.
                                                   581.
     0.64
               0.54
                         0.76
                                   1.25
                                                   813.
                                                                     3.
                                                                             2.
          FS1
                  FSZ
                           FS3
                                            FZA
                                       F2
                                                     F2B
                                                           FЭ
 113.75 118.68 118.97 118.98 118.69 118.96 118.97 118.98 118.98 118.98 0.32 0.30 0.08 0.07 0.30 0.08 0.08 0.07 0.05 0.05
                                      9.30 0.08 0.08 0.07 0.05 0.05
RZ FZA RZB R3 R3A R3B AZ AZA AZB A3 A3A A3B
0.365 0.319 0.371 0.851 0.769 0.775 0.093-0.006-0.007 0.003 0.000 0.001
0.185 0.147 0.148 0.064 0.094 0.085 0.174 0.107 0.088 0.023 0.008 0.010
 TP2A TP2B TP3A TP3B
137. -372. 138. -368.
                            NZZA NZZB NZZA NZZB
                                                        SNR2A SHR2B SNR3A SNR3B
                          7. 6. 5. 4. -14.8 -14.7 -11.9 -11.9
3. 3. 1. 1. 1.0 1.0 0.7 0.7
      69. 6Z. 61.
10.1 10.1 10.5 10.7 -3.6 2.75 2.45 -3
0.5 3.5 0.8 0.9 0.0 0.15 0.45
NFSA INFSB INFSB INFSB
                                                      2.45 -3.9
```

'EED : 21.5 ( 0.91) KTS

OFFSET : 1.487141 ( 0.001030) HZ

```
RECVR : 11 FEB 79A - BLOCK SUMMARY : 22: 7: 59 TO 23: 5: 40 ( 2: 41)
M7EXSA - SPECIAL HIGH RATE VERSION FOR 178 NSUA
           NHO = 16 , INFO = NSUA-NUSC780
30 OCT 78 AT 1105 HR ( RETYPED 05 JAN 78 AT 0757 HR )
NA NB ND NE NG NH0 NH1 N1 NL NH NO NG NS NSL NT0 NT1
64 4036 15 2048 10 16 256 512 6 240 32 4 409 415 2 5
  ZSHLIM FTHRSØ FTHRS1 R2CUTØ R2CUT1 R2CUT2 DF1 DF2 NE1
0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000 4095
                                                                                      NE1 INVFLG
          K STREAM FOR MTEXS
12 CCT 78 AT 1330 HR
NK : 4 NIV : \ 512 NOV : 32
M7BX3 THROUGH CELTHRA CHANNEL AT -12.0 58
       THIST = 119. ( 21.5 KT ) , INFO = HSUA-NUSC78
22 JAN 79 AT 0759 HR

STARTING TIME : 22 : 7 : 59 : 0 NO = 4

CENTER FREQUENCY : 204.800 CLOCK FREQUENCY : 0 819. 200
     277. BURSTS /332
                                               2770, SYMBOLS
                                                                  0.136101/ 0.076173 PE(SYM)
        377./ 211. SYMBOL ERRORS
  MEOL ERRORS BY LOCATION : 24. 36.
                                                                           40.
                                                    46.
                                                                 29.
        18.
                  54.
                                                   30.
                                                                15.
                                                                          21.
                             15.
                                        17.
                  21.
        30.
                   34.
                               L2
                                                              TS0
                                                                                              T53
                               L2 L3
6.94 11.72
                                                                         T51 T52
        LO
                   L1
                                                              377.
                                                                                      -0.
                                                                             0.
        3.9<del>9</del>
                   4.50
                                0.7Z
                                                                                       3.
                                                                                                  З.
                                                                 739.
                                            1.43
        0.54
                    0.50
                                                         F2A F2B
                                                                          F3 F3A
  FS0 FS1 FS2 FS3 F2 F2A F2B F3 F3A F3B 118.78 118.73 118.98 118.98 118.74 118.97 118.97 118.99 118.98 118.99 0.32 0.33 0.08 0.07 0.34 0.08 0.07 0.06 0.05 0.05
 RZ RZA RZB R3 R3A R3B AZ AZA AZB A3 H3H COM

0.276 0.207 0.259 0.763 0.594 0.662 0.083-0.006+0.003 0.001-0.000 0.000

0.165 0.140 0.150 0.112 0.133 0.125 0.188 0.160 0.139 0.021 0.020 0.005
                                                     0.083-0.006-0.003 0.001-0.000 0.000
  TF2A TF2B TF3A TF3B NZ2A NZ2B NZ3A NZ3B SNR2A SNR2B SNR3A SNR3B 144. -370. 138. -371. 3. 8. 5. 5. -15.4 -15.3 -13.0 -12.9 66. 99. 63. 62. 5. 9. 2. 2. 1.1 1.1 0.9 6.9
  NF2A INF2B INF3A INF3B S3 Len( 869.) L1N( 44.) NDBV( 53.)
e.s 9.1 8.8 9.8 -2.7 2.75 3.08 -3.5
t.0 1.0 8.9 0.9 0.9 0.0 0.15 0.62 0.1
```

\* \* \*

'EED : 21.5 ( 0.01) KTS

\* \* \*

OFFSET : 1.487211 ( 0.000948) HZ

RECVR : 11 FEB 784 - BLOCK SUMMARY : 113: 7: 54 TO 114: 9: 3 ( 25: 9) 78X3A - SPECIAL HIGH RATE VERSION FOR '78 NSUA NHO = 16 , INFO = NSUA-NUSC780 30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR ) NB ND NE NG NHO NH1 NI NL NH NO NG NS NSL NTO NT1 NW 096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 16 64 4096 15 2048 10 ZSHLIM FTHRS0 FTHRS1 R2CUT0 R2CUT1 R2CUT2 DF1 0.200 3.235 3.730 0.100 0.100 0.100 1.000 DF1 DF2 NEI INVFLG 1.000 4096 K12013 K STREAM FOR M78X5 Paris = . 66 12 OCT 78 AT 1330 HR NIV : 512 NOV : 32 M78X3 THROUGH CELTHRA AT -13. DB SNR TWIST = 119. ( 21.5 KT ) ; INFO = NSUA-NUSC78 23 APR 79 AT 0754 HR STARTING TIME : 113 : 7 : 54 : 0 NO = CENTER FREQUENCY : 204.800 CLOCK FREQUENCY: 9 819. 200 1720. SYMBOLS 10320. BITS 172. BURSTS /387 0.279070/ 0.168023 PE(SYM) 480.7 289. SYMBOL ERRORS JYMBOL ERRORS BY LOCATION : 44. 45. 52. 50. 41. 58. 55, 38. 59. 35. 21. 25. 34. 25. 35. 31 . 34, 22. 19. 39. T50 TS1 TS2 TS3 L1 LZ L3 9.52 157. 0. 3.77 4.20 6.13 0. -1. 0.65 1.49 723. 3. 0.39 0.35 FS3 F2 FZA FZB F3 FSZ FS1 118.72 118.96 118.98 118.98 118.98 118.99 118.75 118.73 118.98 118.99 0.32 0.10 0.08 0.08 0.09 0.07 0.09 0.31 80.0 0.32 R3 RSA RSB AZ AZA AZB A3 A3A A3B RZ RZA RZB 0.182 0.145 0.192 0.622 0.441 0.507 0.056 0.009-0.013 0.002-0.007-0.007 2.208 0.177 0.145 0.024 0.054 0.054 0.152 0.127 0.134 0.151 0.164 0.161 NZ2A NZ2B NZ3A NZ3B SNR2A SNR2B SNR3A SNR3B TPZA TPZB TPSA TPSB 7. 6. -15.8 -15.8 -13.9 -13.8 4. 3. 1.2 1.3 1.0 1.1 187. -362. 189. -374. 13. 7. 11. 70. £8. 68. **S**5. 6. Lan( 1545.) Lin( 117.) NDBV( 62.) INFZA :NFCB INFSA INFSB 53 2.75 3.18 -3.8 -3.9 9.1 8.1 9.3 9.2

0.16

\* \* \*

3.0

3.3

0.9

0.9

0.9

oreed: 21.5 ( 0.02) KTS

\* \* \*

0.57

OFFSET: 1.487311 ( 0.001118) HZ

0.1

RECVR : 11 FEB 79A - BLOCK SUMMARY : 149: 7: 49 TO 150: 8: 50 ( 25: 1) BX39 - SPECIAL HIGH RATE VERSION FOR '78 NSUA NHO = 16 , INFO = NSUA-NUSC780 30 OCT 78 AT 1109 HR ( RETYPED 05 JAN 78 AT 0757 HR ) NA NB ND NE NG NHO NHI NI NL NM NO NO NS NSL NTO NTI 64 4096 15 2048 10 16 256 512 6 240 32 4 409 415 2 5 ZSHLIM FTHRS0 FTHRS1 R2CUT0 R2CUT1 R2CUT2 ÐF1 DF2 NE1 INVFLG 0.200 3.235 3.730 0.100 0.100 0.100 1.000 1.000 4096 K12013 X STREAM FOR MTBX5 12 OCT 78 AT 1330 HR 4 NIV : 512 MISS = . 832 NOV: 32 H78/3 THROUGH CELTHRA AT -14.0 DE SNR THIST = 119. ( 21.5 KT ) ; INFO = MSUA-NUSC78 29 MAY 78 AT 0749 HR STARTING TIME : :49 : 7 : 49 : 0 CENTER FREQUENCY : 204.500 NO = 4 CLOCK FREQUENCY : 0 819. 290 64. BURSTS /382 640. SYMBOLS 3846. BITS 311./ E42. SYMBOL ERRORS 0.490625/ 0.378125 PE(SYM) STHEOL ERRORS BY LOCATION : 35. 25. 2**5**. 36. 37. 32. 36. -33. 12. 4E. 2. . iż. 21. 22. 32. 18. 30. 38. LĄ L2 L1 L3 TSO T51 TSE TS3 5.69 4.04 5.54 7.49 -92. -0. -9. -Q. 0.33 0.62 4.24 1.34 683. \*\* F51 F30 F31 FS2 F53 F2 F2A F2B F3 F3A F3B 118.70 118.68 118.97 118.98 118.69 115.95 118.96 118.97 118.98 118.99 0.27 9.26 0.09 0.09 0.12 0.09 0.09 0.09 0.09 0.45 6.09 0.69 0.07 0.09 0.05 R2 R7A F2B R3 R3A R3B A2 A3A A3B A3 A3A A3B 0.199 1.290 0.112 0.411 0.231 0.335 0.034 0.025 0.007-0.313-0.034-0.008 0.110 0.105 0.110 0.177 0.160 0.158 0.227 0.229 0.215 0.080 0.102 0.090

INTO INTO INTO INTO INTO 53 LONG 1973.1 LING 75.) NDBV/ 95.

TP2A TP2B TP3A TP3B N22A NZ2B NZ3B SNR2B SNR2B SNR3B SNR3B

6.7 0.0 S 3.8 9.0 0.15 0.49 0.1

SPEEL: 21.5 ( 0.02; KTS 0FFSET; 1.487070 ( 0.001079) HZ

\* \*

10. 7. 11. 9. -16.7 -15.7 -14.9 -14.9 10. 7. 11. 7. 1.5 1.7 1.3 1.5

\* \* \* |

78. 35. 58.

#### PART 4

COMPUTER REQUIREMENTS FOR THE M7

CONSTITUTE STEERS

2 MARCH 1979

# Contents

			Pag
1.	Int	roduction	1
2.	Har	dware Requirements	4
	2.1	Speed Requirements	4
		2.1.1 Synchronization Speed Requirements	5
		2.1.2 Information Decoding Speed Requirements	8
	2.2	Memory Requirements	10
		2.2.1 KFILE storage	11
		2.2.2 Input Buffer	12
		2.2.3 Synchronization Files	12
		2.2.4 Working Areas	13
		2.2.5 Program Storage	15
		2.2.6 Summary of Memory Requirements	
3.	Soft	ware Development Requirements	19
	3.1	Size and complexity of the present M7 implementation	21
	3.2	Software development software	23
		3.2.1 Operating system	23
		3.2.2 High level language	24
		3.2.3 Program development system	25
	3.3	Software evaluation	26

# List of Tables

<u>Table</u>	<u>Title                                    </u>	Pages
1	Relevant M7 Farameters	1
2	M7BX3 and M7BX4 Characteristics	3
3	Hardware configurations of ACS computers	4a -
4	Software storage requirements	17
5	Memory requirements summary	18
6	Existing M7 software composition	22

#### 1. Introduction

In order to implement the M7 communications system, the computer selected for the task must meet requirements of speed of execution, memory size and software development capability. With the exception of the latter of these requirements, the specific requirements depend strongly on the parameters of the version being implemented. This paper discusses, with examples, these three major requirements.

To understand the material presented, familiarity with the M7 system and its associated nomenclature will be required. An adequate summary for this purpose is contained in Reference 1, which should be available to the reader. Of the many parameters defined in Reference 1, those shown in Table 1 below will be relevant here:

Table 1: Relevant M7 Parameters (Table Parameters)

Parameter	Definition
NA	No. of symbols in alphabet
N <sub>B</sub>	No. of complex samples/burst
$N_{\mathbf{D}}$	No. of time dilation bins
NE	No. of complex samples between receiver input vectors
N <sub>G</sub>	No. of symbol positions/burst
$N_{\underline{L}}$	No. of bits/symbol (N <sub>L</sub> = log <sub>2</sub> N <sub>A</sub> )
NM	No. of integer line searches $(N_M = N_D \cdot N_W)$
NQ	System Q
N <sub>S</sub>	No. of complex samples/symbol
N <sub>TØ</sub>	No. of fractional line searches/integer line
N.	No. of line searches/time dilation bin

- In some applications, the single  $N_B$  long burst described in Reference 1 will not be sufficient to transmit the necessary information. That is, the desired message length is greater than  $N_L \cdot N_G$  bits. To accomodate such applications, the M7 system can be logically extended by constructing the transmission from  $N_Z$  consecutive  $N_B$ -long blocks, where each  $N_B$ -long block has the same structure as the original block, but is based on a different random bit stream. This allows  $N_Z \cdot N_L \cdot N_G$  bits to be transmitted in a single burst without introducing any structure into the transmission. At the receiver, primary synchronization is performed on the first block only, later blocks being synchronized by the equivalent of the secondary synchronization search. The current implementation, for research purposes, is limited to the single block mode ( $N_Z$  = 1).
- The discussion of computer requirements versus system

  parameters can become an abstract exercise very quickly. To provide

  a tangible basis for this discussion, two current versions of the M7

  system will be considered relative to two existing hardware configurations.

  The implementation approach considered will be that of the existing implementation other approaches may be worth pursuing, but the one given here appears straightforward.
- The two versions of the M7 system considered in the examples are sketched in Table 2. The M7BX3 version is directed at investigating the tactical submarine to submarine communication problem and has a moderate bit rate and a moderate range capability. The M7BX4 version

Table 2: M7BX3 and M7BX4 Characteristics

(Table classified

Characteristic	<u>M7BX3</u>	<u>M7BX4</u>
Application	Tactical	Strategic
Center frequency, Hz	204.8	150
Bandwidth, Hz	51.2	50.0
Burst duration, sec	80.0	819.2(13.7 min)
Block WT product	4096	4096
Modulation	64-ary biorthogonal	64-ary biorthogonal
Symbol Duration, sec	8.0	40.96
Symbol WT product	409	2048
Bit rate, bits/sec	.750	.146
Bits per burst	60	120
Doppler uncertainty, Kt	<u>+</u> 21.5	±.25
Nominal Range, nm	100	500
Operating (S/N) dB for $P_E$ (BIT) = .0001, estimated from simulation data	-8.0	-10.0

is intended to approximate a strategic, low bit rate, long range communication system. Here, the desired message length requires  $N_Z = 10$ . Consequently, M7BX4 as described in Table 1 is not implementable in full on the existing system.

amples are based on existing Acoustic Communication Studies equipment.

Consequently, a great deal of solid information concerning execution times, program size, etc. is available for both. Table 3 gives the salient information for a system based on the Texas Instruments 980A computer and for the same system when a Floating Point Systems AP-120B array processor is added. The 980A alone system represents roughly the typical minicomputer based organization, the 980A with AP system represents the typical minicomputer plus array processor organization.

### 2.0 Hardware Requirements

The M7 system employs large time-bandwidth product signals and operates with substantial time/frequency of arrival uncertainty. These features place stringent requirements on the computation speed and memory size of the hardware. The sections below describes each of these requirements.

# 2.1 Speed Requirements

In order to synchronize with the incoming signal, that is to detect its presence and estimate its time and frequency of arrival, a large number of calculations must be performed in real time. Once synchronization has been obtained, further extensive calculations are required to determine the transmitted message. Each operation imposes

Table 4a: Hardware Configurations of ACS

Computers (This table (Software Development Equipment Excluded from this Table)

	Syster	
Characteristic	980A Alone	980A/AP-120B
Hardware Arithmetic Speed: (µS)		
Double Precision Integer Add	4.0	4.0
Single X Single Integer Multiply	7.25	7.25
Floating Point Add	150	150
980A Floating Point Multiply	240	240
Floating Point Add	Na compromission de	∿ .166
AP120B Floating Point Multiply		<b>∿ .166</b>
Software Speed: (ms)		
Arithmetic	16 bit block, floating point	38 bit floating point
Complex Array Multiply/Point	.303	.001
Complex FFT N = 1024	1240	6.93
2048	2680	16.68
4096	5847	33.16
8192		77.31
Memory Configuration (words)		
CPU Memory (16 bit)	65536	65536
Moving Head Disk (16 bit)	1120000	1120000
Main Data (38 bit)		40960
Table (38 bit)		3072
Program Source (64 bit)		1024

its own requirements on the computer speed.

### 2.1.1 Synchronization Speed Requirements

Only the primary search in the synchronization process is significant in terms of calculation speed. As indicated in Reference 1, each primary search consists of  $N_{M} \cdot N_{TO}$ . Doppler bin searches over an  $N_{B}$  long input vector. For real-time operation these searches must be completed in  ${}^{N}E/N_{B} \cdot T_{B}$  seconds where  $N_{E}$  is the number of complex samples between consecutive input vectors and  $T_{B}$  is the time duration of a block of  $N_{B}$  complex samples,

$$T_{B} = N_{B} \frac{N_{Q}}{f_{P}}$$
 (1)

Each Doppler bin search requires the following minimal calculations:

- 1. Array multiply between  $X_{o}(f)$  and A(f)
- 2. Inverse Fast Fourier Transform (FFT) to yield y(j, k)
- 3. Calculation of z(j, k) (Ref 1, Eqn 29)
- 4. Calculation of lo (Ref 1, Eqn 30)

with existing software steps 3 and 4 occupy a time equivalent to an array multiply. Thus the calculations per Doppler bin are equivalent to one FFT and two array multiples.

To provide a simple, but useful bound on computer speed for synchronization, the maximum allowable time for an  $N_B$ -long FFT,  $T_{SYNCH}^k$ , will be computed based on the assumption that the time for the two array multiplies can be neglected. This bound is particularly convenient because it is close to the actual time for most versions of the M7 system

<sup>\*</sup>All operations performed by the receiver are over complex array variables.

(2 <<  $\log_2$  N<sub>B</sub>) and calculation times for a given size FFT can often be found from manufacturer's data. Note, however that  $T_{\text{SYNCH}}^{\ddagger}$  is a strict upper bound, a computer which performs an N<sub>B</sub>-long FFT in exactly  $T_{\text{SYNCH}}^{\ddagger}$  can not operate in real time.

To perform  $N_M \cdot N_{TO}$  Doppler bin searches each of duration  $T_{SYNCH}^*$  in  $N_B \cdot N_B$  seconds, the following equation must hold:

$$T_{\text{SYNCH}}^{\star} = \frac{N_E}{N_B} \frac{T_B}{N_M \cdot N_{TO}}$$
 (2)

where  $N_M$  is the number of line spacings (DFLINE =  $^{1/}T_B$ ) required for the Doppler search as described in Reference 1.

Equation 2 becomes more useful when  $N_{\underline{M}}$  is written as a function of the Doppler uncertainty, |V|. The frequency offset, DF, as a function of |V| is given by:

$$DF = \frac{|V|}{C} f_{R}$$
 (3)

From equation 28 of Reference 1,

$$DF_{RANGE} (Hz) = \frac{f_R}{N_Q \cdot N_B} N_M$$
 (4)

since the search range is two sided and symmetric about  $\mathbf{f}_{\mathbf{R}^*}$  . Solving for  $\mathbf{N}_{\mathbf{M}}$  yields

$$N_{M} = 2^{|V|}/c N_{Q} \cdot N_{B}$$
 (6)

Then equation 2 becomes

$$T_{\text{SYNCH}}^{*} = \frac{C}{2|V|} \frac{N_{\text{E}}}{N_{\text{B}}} \frac{1}{N_{\text{T0}}} \frac{1}{f_{\text{R}}}$$
 (7)

If the search strategy implemented in M7BX3 is applied, the above equation can be simplified further. In M7BX3, a 50% overlap in the time domain ( $^{N}E/N_{B} = \frac{1}{2}$ ) and a  $\frac{1}{2}$  line spacing frequency search interval ( $N_{T0} = 2$ ) are incorporated in the primary search. Further, take C = 5000 ft/sec. Then Equation 7 becomes

$$T_{SYNCH}^{*} = \frac{370.041}{f_{R}} \frac{1}{|V|}$$
 (8)

where |V| is expressed in Knots (Kt). Note that  $N_B$  does <u>not</u> appear explicity in Equation 11, but that by definition  $T_{SYNCH}^*$  is the time to perform an  $N_B$ -long FFT.

- The values for T<sub>SYNCH</sub> for the M7BX3 and M7BX4 systems of Table 1 are 84 ms (milliseconds) and 9.87 seconds respectively. Since 84 ms is greater than the published 4096 transform time for the 980A/AP system of Table 3, M7BX3 is implementable on that hardware. M7BX3 is not implementable on the 980A alone hardware. In the case of the M7BX4 version, it is implementable with ease on the 980A/AP hardware and may implementable on the 980A alone hardware.
- Since the Doppler range for the M7BX3 system has been deliberately set as the maximum implementable by the 980A/AP hardware, further conclusions can be drawn. Since T\*SYNCH for the M7BX3 system is about 2.5 times greater than the published 4096 transform time (33 ms) a crude, but useful estimate of the actual required 4096 transform time for the M7BX4 system can be obtained by dividing the corresponding T\*SYNCH by 2.5. This yields a requirement for a 4096 transform time no longer than 3.95 seconds for the M7BX4 system and attempts to include the many overhead calculations necessary in an

actual system. Since 3.95 seconds is less than the published transform time (5.85 sec) for the 980A above hardware, an implementation of M7BX4 on that hardware may <u>not</u> be possible, contrary to the T\* calculations of the proceeding paragraph.

# 2.1.2 Information Decoding Speed Requirements

Because the information decoding operation of the M7 system takes place only after a detection by the synchronization operation, its time constraints are more flexible. If transmitted messages are known to be separated by some minimum time interval or if the arrival of more than one message in an interval is unlikely, the receiver can simply ignore its input after the detection takes place and devote its entire calculational resources to information decoding. This yields an interval, Talank, after ach correct detection or false alarm in which an incoming signal will be ignored as the receiver is effectively "blanked out". With current thresholds set to yield less than one false alarm in 36 hours, blanking due to false alarms will be negligible for most applications. Of course, sufficient computer speed eliminates the need for blanking.

The information decoding operation is somewhat complicated and consequently an explanation of each sub-operation is beyond the scope of this paper. Three computationally important components of the information decoding operation are listed below along the number of FFT's required:

Component

Transforms Required

Secondary Search

ě.

2 - DF - NT1

Doppler removal/probe extraction

105

Symbol filtering

2 · N . · N .

Again in deriving a timing bound, the time required for array multiplies will be neglected. The above figures do include transforms for the bootstrapping operation, however. For a secondary search equivalent to that of M7BX3 (DF = 1, NT1 = 5), the total number of transforms becomes  $115 + 2 \cdot N_A \cdot N_C$ , with the relative importance of the first and second terms dependent on the size of the signalling alphabet,  $N_A$ , and the number of symbols per block,  $N_C$ .

For real-time operation with no blanking, the 115 +  $2 \cdot N_A \cdot N_S$   $N_B$ -long transforms must be performed in  $T_B$  seconds. Let  $T_{INFO}^*$  be the transform time for an  $N_B$ -long transform, then the following equation must hold:

$$T_{INFO}^{*} = \frac{N_{O} \cdot N_{B}}{(115 + 2N_{A} \cdot N_{C}) f_{R}}$$
 (9)

If the transform time on a machine is greater than  $T_{\overline{INFO}}^{\star}$ , some amount of blanking of the receiver input will be required. Let  $T_{\overline{FFT}}$  be the actual time required for an  $N_B$ -long transform, then the minimum length of the post-detection blanking interval,  $T_{BLANK}^{\star}$ , is given by

$$T_{BLANK}^{*} = (T_{FFT} - T_{INFO}^{*}) (115 + 2N_A N_S) N_Z$$
 (10)

Because of the array multiplies and other necessary overhead calculations, the actual blanking interval will be larger than  $T_{\rm BLANK}^{\star}$ .

ms and 221 ms respectively. The transform times of Table 1, Table 3 then indicate that M7BX3 can not implement real-time on the 980A alone configuration, but can be implemented on the 980A/AP configuration. The M7BX4 system cannot be implemented in real-time on the 980A alone configuration either, while it can be implemented with ease on the 980A/AP configuration. The required minimum blanking intervals

Table 1, Table 3 then in
M7BX4 system cannot be implemented in real-time on the 980A alone configuration either, while it can be implemented with ease on the 980A/AP configuration. The required minimum blanking intervals

Table 3 then in
M7BX4 system cannot be implemented on the 980A alone configuration either, while it can be implemented with ease on the 980A/AP configuration. The required minimum blanking intervals

Table 3 then in
M7BX4 system cannot be implemented in real-time on the 980A alone configuration either, while it can be implemented with ease on the 980A/AP configuration. The required minimum blanking intervals

Table 3 then in
M7BX4 system cannot be implemented in real-time on the 980A alone configuration. The M7BX4 system cannot be implemented in real-time on the 980A alone configuration either, while it can be implemented with ease on the 980A/AP configuration. The required minimum blanking intervals

Table 3 then in-

### 2.2 Memory Requirements

The second major hardware requirement for the M7 system is for memory space. Five major functional requirements for storage can be designated:

- 1. KFILE storage
- 2. Input Buffer
- 3. Synchronization Files
- 4. Working Areas
- 5. Program storage

A variety of approaches to satisfying these requirements can be considered in implementing the system. Generally, a trade-off opportunity between speed of execution and memory size/cost can be made. The trade-offs indicated in the following discussion again parallels that of the current implementation.

### 2.2.1 KFILE Storage

8

The structure of the M7 system is based on a sequence of random bits, known as the KFILE. This sequence must be available to the receiver in order to synchronize and decode the transmission. The number of bits in the KFILE,  $N_{\rm KB}$ , is given by

$$N_{KB} = N_Z N_B (1 + N_A/2)$$
 (11)

For the M7BX3 and M7BX4 systems,  $N_{KB}$  is 135, 168 and 1,351,680 bits respectively. In terms of 16 bit computer words, a more useful measure, these values are 8,448 and 84,480 words respectively.

In the current implementation of the M7 system, KFILE's are generated by a laboratory noise generator and stored on a moving head disk file. This file, which contains other vectors needed by the receiver, is called the VFILE. In an operational system the kinker (and consequently the VFILE) would probably be changed in a periodic basis. Consequently a means for entering as well as storing the KFILE would be necessary.

One approach to these problems is to interface the system to an approved cryptologic sequence generator and have it produce the needed bits on command. If an approved sequence generator cannot be used, alternative algorithms in conjunction with devices such as the National Bureau of Standards Data Encryption Standard (DES) might be satisfactory. Thus the KFILE storage requirement can be satisfied by providing the necessary storage and input capability or by interfacing KFILE generation hardware.

#### 2.2.2 Input Buffer

Because the receiver operates asynchonously with the input data, the input must be buffered to ensure the necessary data is available to the receiver. The extent of this buffer depends on the speed of the receiver in performing both the synchronization and information decoding tasks. In general, a shorter input buffer becomes acceptable as the receiver speed increases. Determination of the minimum size of the input buffer is an involved problem which has not been pursued. The current implementation has an input buffer of  $3N_B$  complex pairs (6  $N_B$  real words) maintained on a moving head disk file. This buffer size has been sufficient for existing versions of the system having  $N_Z = 1$ . If  $N_Z$  is greater than 1, a longer buffer may be . Tassary.

### 2.2.3 Synchronization Filer

The M7 receiver synchronization process requires a search over N<sub>D</sub> time dilation bins where each time dilation bin is centered on a time-distorted replica of the transmitted probe component. With the exception of the central bin, the construction of the time-distorted replicas requires a substantial amount of calculations. Consequently, in the current implementation all of these time-distorted replicas are pre-computed and stored as synchronization files, a component of the VFILE on the moving-head disk unit. With this approach N<sub>D</sub> vectors of N<sub>B</sub> complex words or 2·N<sub>D</sub>·N<sub>B</sub> real words are required. For M7BX3, 122,880 real words are required for the synchronization files.

If  $N_D = 1$ , that is, if  $N_M$  is less than about 16, then only the central time dilation bin is searched. In this case, which applies to the M7BX4 versions, no need for a pre-computed replica exists and the synchronization file can be eliminated.

### 2.2.4 Working Areas

substantial working areas in memory. For example, in the synchronization process, the transform of the input data, X(f), is multiplied by the time-dilated replica's transform, A<sub>j</sub>(f), then inverse transformed to the time domain to yield y(i, j). Because X(f) and A<sub>j</sub>(f) are needed for each of N<sub>W</sub> pure frequency offsets within a time dilation bin, at least 3 N<sub>B</sub>-long complex vectors must be resident in the work area. In fact, an additional N<sub>B</sub>-long complex vector is used in the current implementation to allow an 18% speed-up in the inverse FFT. Similarly, the Doppler removal algorithm requires at least 4 N<sub>B</sub>-long complex vectors. The equivalent of another N<sub>B</sub>-long complex vector is needed for scalars and miscellaneous tables, bringing the total requirement to 10 N<sub>B</sub> words in the working areas. For either M7BX3 or M7BX4, this means 40,960 words should be available.

In the current implementation on the 980A/AP hardware, the working areas are located in the array processor main data memory. An additional 3072 words of random access table memory serve as storage for trignometric constants, etc. Because the words of either of these memories are composed at 38 bits each, the size of the work and constant storage areas in the array processor (1.67 x  $10^6$  bits) is greater than that of the 980A itself (1.05 x  $10^6$  bits). Thus neither M7BX3 nor M7BX4

- hardware. Implementation with 16 bit integer arithmetic on the 980A alone hardware would be very difficult as only 21,504 words would be available for the program itself. Consequently, these versions are implementable only on machines with an effective address space significantly larger than 32,768, or with an array processor having approximately 44,000 words of data memory.
  - In the present implementation of the system two additional N<sub>B</sub>-long working areas have been incorporated into the 980A memory. These areas are necessary to speed the transfers of vectors on the moving head disk file to the array processor and to facilitate the bootstrapping operation. If the KFILE synchronization files were directly accessable by the array processor, one of these vectors could be eliminated. The other vector is used in the re-construction of the transmitted signal during bootstrapping and could be eliminated if the re-construction algorithm was readily performed in the array processor. Consequently, limitations on either hardware or software may increase the working space requirements beyond those indicated above.

#### 2.2.5 Program Storage Requirements

The software program which implements the M7 system also requires space in the computer memory. Perhaps more than any other requirement, a estimate of the extent of computer memory needed is dependent on the particular machine selected and the details of the program organization. Nevertheless, the discussion below will be helpful in estimating the memory requirements for program storage, as long as a resolution beyond about 16K 16 bit words is not sought.

The present implementation of the M7 system consists of a disk initialization program (VSET) which precalculates the necessary VFILE vector and a real time program (RECVR) which does the actual reception. Because the disk initialization program is performed only once prior to system operation, it will not be considered further.

Six functional groups into which the program memory space can be partitioned are:

- 1. Monitor System Software
- 2. General Purpose Subroutines
- 3. Input Buffer Manager
- 4. Receiver Tasks and Subroutines
- 5. Large Arrays
- 6. Miscellaneous Arrays

The first group includes non-specific operator interaction, hardware device servicing and task control functions. The second group contains subroutines of a general nature, mostly arithmetic. Software in groups one and two is <u>not</u> specific to the communication problem and, ideally, would be provided as a standard product by the hardware manufacturer. The input buffer manager allows the real-time input data to be processed

in a convenient manner. Although specific to real-time applications, it is not peculiar to the communication problem. Group four contains all tasks and subroutines which are specific to the communication problem - no part of group four is likely to be available from other sources. Groups five and six cover working areas in the mainframe. The space requirements of group five could potentially be eliminated under certain hardware conditions as discussed at the conclusion of the preceeding section. The space requirements of group six represent the size of miscellaneous array storage required to run M7, beyond the working areas already discussed.

Table 4 below gives the current size in 16 bit words of each of the six software groups.

And the second of the second o

Table 4: Software Storage Requirements

(Based on RECVR/26 Oct 78A)

(Table

Group	Contents	Storage (16 bit words)
1	Monitor system software	7,247
2	General purpose routines	9,453
3	Input buffer manager	9,377
4	Receiver tasks and subroutines	11,171
5	Large arrays	16,384
6	Miscellaneous arrays	3,086
	Total	56,718
	Group 5	- <u>16,384</u>
	Total (less Group 5)	40,334

Several cautions must be considered in conjunction with Table 4. First, the monitor system available is extremely memory and time efficient. A general purpose system such as provided by a manufacturer to all users would probably be larger. Second, the input buffer routines are for a single channel only and do not perform any filtering function. Third, although some space is devoted to statistical functions associated with the research purposes of the system, an operational system would almost certainly require further storage for purposes such as interference rejection, error detecting-correcting algorithms, message handling etc. These considerations lead to a first estimate of at least 65K words for program alone for an operational, single channel system.

### 2.2.6 Summary of Memory Requirements

The results of the preceeding memory requirements discussion are summarized in Table 5. Two hardware configurations, different from those considered previously are given. Configuration A assumes memory

Table 5: Memory Requirements Summary (16 bit words)

System (Table classified

	M7BX3 Configuration		M7BX4 Configuration	
Requirement	A	<u>B</u>	<u> </u>	B
KFILE storage*	8448	NAME .	84,480	-
Input buffer*	24,576	24,576	24,576	24,576
Synchronization files*	122,880	122,880		-
Working areas	44,000	44,000	44,000	44,000
Program Storage	<u>56,718</u>	40,334	56,718	40,334
Totals	256,622	231,790	209,744	108,910

<sup>\*</sup>This storage is implemented in bulk storage moving head disk in the current system.

usage comparable to the present system and can be considered pessimistic (i.e. larger than absolutely necessary). Configuration B is based on the assumption of an on-line KFILE generator and homogeneous memory in the hardware and consequently has a much smaller memory requirement.

Both the M7BX3 and M7BX4 versions of the system are shown.

system requires far more memory than is directly addressable with current 16-bit minicomputers. Consequently any hardware on which the M7 system is to be implemented must have either a larger address space or a convenient memory paging feature. Alternatively, a trade-off between execution speed and addressability could be made by incorporating a bulk storage device. Probably the best solution is simply to have a large homogeneous address space. If this is not available, a partitioning into two memory units, one of which has a larger address space would be suggested. Only as a last resort would the paging capability associated with a bulk storage device be appropriate, due to the resulting software complexity and loss of execution speed.

### 3. Software development requirements

Implementation of the M7 system has two major elements:
hardware and software. While hardware presents significant bounds on
the maximum possible capability of the system, i.e. Doppler range,
software determines how close to these bounds the system will actually
operate. Perhaps the most important area of application for the above
statement is in reliability. A communication system with an error rate
of .001 can have its performance degraded by a factor of two due to an
error in programming which occurs only once in a thousand operations.

Detection of such errors in systems with stochastic inputs can be extremely difficult unless the software is generated and evaluated with extreme care.

The following sections discuss the requirements for generation and evaluation for the M7 system. Before going into these requirements a brief comment on the size and complexity of the present software implementation will be presented as a point of reference.

### 3.1 Size and Complexity of the Present M7 Implementation

The size of a software task is important in determining the approach to accomplishing it. For example, the software for a microwave oven controller can be efficiently generated with less sophisticated tools than those for a ballistic missile defense system. In the first case, programming in machine code and testing by near-exhaustion may be appropriate. In the latter, high level languages and intricate software verification programs are necessary. The software for the existing M7 communication system clearly falls in between these extremes, and some measure of the size and complexity of the software is necessary to select appropriate software development techniques.

In section 2.2.5, the program size of the M7 system (less large arrays, Group 5) was given as 40,334 16 bit words. This is one very crude measure of the extent of the software task. Alternatively, consider the breakdown of that same program in terms of number entry points and lines of source code as indicated in Table 6 below. Each entry point signifies a piece of the overall software mass, so that in a rough sense, about 210 identifiable software modules must be interconnected. Each line of source code represents one line of program printout which must be carefully designed, test and maintained.

Table 6: Existing M? Software Composition;

(26 Oct 78A) (Table

Group	Туре	Entry Points	Language	Source Code Length (Lines)
1	System	61	980 A.L.	(6602)*
2	G.P. Routines			
	980A	73	980 A.L.	
	FAP-G.P.	21	FAP A.L.	
	FAP Special	9	FAP A.L.	382**
3	Buffer Task & Routines	18	F	1581
4	Comm. Tasks	4	7	1143
4	Comm. Routines	15	F	1860
		4	980 A.L.	626***
•	Support Programs	5	F	2458
		- Angelone		
			A.L.	1008 12.5%
			F	7042 87.5%
	Total	210	Total	8050

<sup>\*</sup> Normally provided by manufacturer, not counted in total below.

<sup>\*\* 64</sup> bit microcode word/line approximately 4 times more difficult than 980A A.L.

<sup>\*\*\* 446</sup> lines of A.L. format conversion routines, remainder writable in Fortran.

Although various technical definitions of program complexity have been proposed, the concept of complexity considered here is more qualitative - given an anomaly or software "Glitch" the complexity of the program is a measure of the time required to find the cause of the problem. The present system has been developed via the traditional method of independent subroutine development and testing followed by staged integration of the routine into the system. This approach is an excellent one, but its fundamental weakness is that the subroutine can not be adequately tested independently, as the variety of inputs is too great. Consequently, the union of a number of verified subroutines can be a program that works on only a small subset of inputs. More importantly, with stochastic inputs the particular input causing an anomaly may be infrequent and hard to detect. Thus, the complexity of the system, as implemented, is at least moderate; an operational system would be more complex.

### 3.2 Software Development Tools:

The reliability of the software for an implementation will depend on the quality of the tools of its development as well as the programmer's skill. Only three major and essential tools will be discussed here: operating system, high level programming language and program development software.

#### 3.2.1 System Software:

Because the manufacturer of the existing 980A system did not provide an interrupt driven operating system until very recently, a special purpose system, more correctly called a monitor system, has been developed beginning in 1973. The present version of this system occupies 7,247 16 bit computer words and involves 6602 lines of source

code. Although the present system works very well, its development, testing and maintenance has been time consuming. For example, in the summer of 1978, a re-entrancy problem was found in the interrupt servicing routines which caused the system to crash mysteriously at a rate of about 2 crashes per month. Such problems are hard to detect - at that rate a hardware failure or power glitch would be suspected.

mentation of the M7 system should have a flexible and reliable operating system provided with it. It should be flexible in the sense that no modification of the fundamental system should be necessary to accommodate the implementation of the communication system. Driver modules for special hardware modules, of course, will be necessary, but they should be short and follow the canonical structure used by the operating system. The operating system should be already well-evaluated for reliability, where the only acceptable indication of this reliability is successful application to real-time problems by a number of independent users, over a period of years.

## 3.2.2 High Level Language:

developed in assembly language (or even machine code), a high-level language would certainly be used by the vast majority of software designers. Indeed, the military is beginning to require use of a high level language for all systems beyond the development stage. The present M7 implementation, exclusive of the monitor system, has 88% of its source code in FORTRAN IV. The remaining 12% of the source code lines are in assembly language for reasons of necessity (i.e. microcode for the array processor), compatibility (i.e. executable by the transmitter

without the FORTRAN library) and convenience (i.e. radix 40 packing and unpacking). If necessary all but 5% of the software (the array processor microcode) could be written in FORTRAN.

FORTRAN is only one of a variety of high level languages suitable for implementing the M7 system and other languages can offer even further advantages. The only critical requirements for such a language is that it should be flexibly interfaced to the operating system and have only moderate overhead. Specifically, all peripheral devices should be handled within the normal syntax of the language, i.e. READ/WRITE statements in FORTRAN. Some languages are so powerful in notation they may not meet the latter requiremen. For example, a program written in BASIC might treat the statement

$$A = B + C$$

has a matrix equation, even for scalar variables. The resulting overhead in execution time would probably be unacceptable. Both these requirements will normally be satisfied by software available from the computer manufacturer.

#### 3.2.3 Program Development System:

To test, modify and maintain the 200 plus modules requires convenient program development system including editors, linkers and subroutine libraries. One measure of the convenience of such a program development system is the time required to change a software module, document the change and the execute the resulting system for evaluation purposes. The program development system from which the current M7, implementation was constructed is implemented on the same hardware (980A) the M7 system runs on and requires about 30 minutes to insert a fully

documented change. Strangely, the majority of this time (20 min) is spent in linking the object modules together.

The lack of automatic source and object dating. In a system with a large number of modules, care must be taken that all of the modules included in an executable program be of the most recent revision level. Enormous difficulties arise when subroutines of a lower revision level are inadvertently mixed into an otherwise correct program. In the present program development system, revision-level dating is performed by the programmer and great care is required to ensure the program uses only current modules. Program development systems on other manufacturer's system should include automatic source and object dating, eliminating this problem.

### 3.3 Software Evaluation:

An essential component of software development for the M7 system is careful evaluation of the system against both known and stochastic signals. This is because of the inherent non-linearity of the processing (superposition does not apply), the wide variety of allowable inputs during operation at sea, and the need for reliability against infrequent, but erroneous events. Only by extensive testing and statistical examination of selected "internal" parameters can the full capabilities of the system be realized.

In order to perform the required evaluation the software must be developed on a system with more peripherals than required by the operational hardware. Specifically, the software development hardware should include a noise source, one or more tape drives, and high-speed printer or display device. The need for each of these items is

discussed below.

main program against fixed inputs is completed, evaluation over carefully controlled stochastic inputs must be performed. The most natural approach to this evaluation is to construct digital synthetic data tapes for the receiver and statistically observe its performance. In the development of the present system, these synthetic data tapes contain signal and noise at precisely controlled signal to noise ratios. The signals included can be at arbitrary Doppler shifts and are passed through pre-specified linear time invariant channels. Further, the time of arrival is randomized to assure adequate synchronization testing. To accomplish this type of evaluation requires a digital tape peripheral and noise source.

Measurement of error performance alone with synthetic data is not sufficient to verify the receiver operation or locate the source of observed problems. Instead, a number of "internal" parameters or their statistics should be available for examination. An "internal" parameter is one which would not normally be available to the operator of a military system, but which checkpoints the performance o: the program's components. For example, in the present implementation of the M7 system, about 50 internal parameters are analysed statistically about every 20 bursts. To provide a means of printing these and similar results, a high-speed printer or plotter is necessary.

The above techniques and equipment yielded significant improvements in the present M7 system. In the time interval since the system was "completed" in June 1978 to the present, February 1979,

ments made. These changes have improved the error performance of a system which seemed to be operating correctly by a factor of at least two. Although much of the experience gained in the interval need not be repeated, a similar test program and associated equipment is necessary for any future implementation.

### PART 5

COMMENTS ON THE MACS

CORRECT TIME MEASUREMENTS

#### 1. Introduction

References 1, 2, 3 and 4 represents the largest and most geographically diverse collection of experimental results available for the design of underwater acoustic communication systems. Because interpretation of these results will effect the design of Navy systems for many years, a critical discussion of the results is appropriate. This paper addresses the coherence time measurements of the MAGS data. Subsequent sections show that the MAGS coherence times are attributable to either interplatform motion or to time of arrival compensation error; so that the measured values are not those for the actual acoustic medium. The performance of large time-bandwidth (TW) systems under comparable interplatform motions is then analyzed, with the important result that large TW systems can operate successfully with burst duration longer than the MAGS coherence time.

If the MACS coherence times are a result of inter-platform motion rather than the acoustic channel, a simple relation between system center frequency and permissible burst duration is available. Indeed the apparent coherence time at 200 Hz will be 2.5 times larger than that measured by MACS at 500 Hz. This means that large TW systems are applicable even when motional effects are present, provided that the center frequency is chosen low enough. Because a large TW system offers significant

<sup>\*</sup>Since the frequency smear is the transform of the time correlation function, the comments given are applicable to that result as well.

(~ 10dB) performance advantages over the conventional incoherent tonal system, this result deserves consideration.

Section 2 reviews the MACS coherence time measurement as presented in Reference 1. The effects of sinusoidal phase modulation on the coherence time is studied in Section 3. Two sources of potential phase modulation: inter-vessel motion and time of arrival estimation error are shown to yield coherence times in the same range as those obtained by MACS. Section 4 analyses the performance of large TW channel measurement systems assuming equivalent phase modulation. Finally, Section 5 provides recommendations for the users of MACS data and suggests a more suitable transmission waveform for future experiments.

### 2. MACS Coherence Time Measurement

- A summary of the MACS coherence technique described in Reference 1 and in Section 2.1 of References 3 and 4 will be given for convenience.
- The basic transmission for the MACS data was a Gaussian pulse of duration 8.839 ms between 3dB points having a bandwidth of 99.848 Hz between 3dB points. Such a pulse has the minimum theoretical TW product of 1.253. Pulses were transmitted at a variety of frequencies from 500 to 3500 Hz, however, this paper considers only the 500 Hz data. These pulses were sent periodically at a rate of about one per second, with a typical interval containing 1000 4000 pulses over 15-60 minutes.

Equivalently: 12.5 ms between 6dB points in time, 141.207 Hz between 6dB points in frequency.

- Received pulses were coherently demodulated to a complex baseband waveform and sampled, yielding complex pairs with 4.096 ms between pairs. Note that the sample interval, 4.096 ms, is equivalent to a 720° phase rotation at 500 Hz. The received pulses are windowed to given  $S_n(\tau)$ , the uncorrected channel response to the n-th pulse.
- The collection of pulse responses  $S_n(\tau)$ , in a given data interval is processed to remove "deterministic" changes in arrival time.

The term "Deterministic" is used here to designate these arrival time changes caused by non parallelism of the actual ships tracks: the time scale of these changes is large compared to the time scales of stochastic fluctuations of the medium, and the separation is effected on the basis of that criterion. (Reference 1, page 9).

Correction is accomplished by calculating the cross-correlation function  $C_{n,k}$  ( $\beta$ ) of the envelope squared of the n-th and k-th pulses. The point of maximum correlation between the first and nth pulse,  $\hat{\tau}_n$ , is the input to the correction process. Here  $\hat{\tau}_n$  is necessarily quantized at the sampling interval 4.096 ms because  $C_{n,k}$  ( $\beta$ ) is an incoherent measurement. Thus the input to the time of arrival correction algorithm is quantized in 720° phase steps.

The measured values of  $\hat{\tau}_n$  are fitted with a 4th degree polynomial over an interval of 300 seconds. A weighting technique is applied at cusps in arrival time occurring between two polynomially-fitted intervals. The points on the resulting smooth curve are designated  $\hat{t}_n$  where  $\hat{t}_n$  is not quantized. The n-th received pulse  $S_n(\tau)$  is shifted in time and phase by  $t_n$  to yield  $\hat{S}_n(\tau)$ , the corrected received pulse response. All subsequent analysis is performed on  $\hat{S}_n(\tau)$ .

A set of complex points  $\hat{H}_n(0)$  representing the complex value of the channel transfer  $\hat{H}_n(f)$  of the carrier frequency is computed:

$$\hat{H}_{n}(f) = \int \hat{S}_{n}(\tau) e^{-2\pi f \tau} d\tau$$
 (2.1)

$$\hat{H}_{n}(o) = \int \hat{S}_{n}(\tau) d\tau \qquad (2.2)$$

where the integration takes place over the previously selected window. The magnitude of  $\hat{H}_n(o)$  is shown in the top center plot of the MACS data.\*\* The power spectrum,  $F_k$ , of the series  $H_n(o)$   $(n=1\dots N)$  is called the frequency smear and is shown in top right plot of the MACS data.\*\* The discrete Fourier transform of  $F_k$  is called the time correlation function,  $R_{\rm HH}(1)$ , and is normalized by  $R_{\rm HH}(o)$  to yield the normalized correlation function,  $\rho_{\rm HH}(1)$ .

References 1 and 2 use a 6-th degree polynomial and presumably the same interval size. Where differences exist between References 1, 2 and References 3, 4 the text describes the most recent data.

<sup>\*\*</sup> In the old format of References 1 and 2,  $\hat{H}_n(o)$  is in the upper right corner of the data (Plot A).

<sup>\*\*\*</sup> Top center (Plot B) in References 1 and 2.

The magnitude of the normalized correlation function is shown in the middle plot of the right hand column in the MACS data.\*

The MACS coherence time is defined as the time offset  $\tau^*$  corresponding to  $i^*$  so that

$$\left|\rho_{\mathrm{HH}}(\mathbf{i}^*)\right| = .4 \tag{2.3}$$

In rare instances more than one solution to Equation 2.3 may be available. In such cases, the minimum value of  $\tau^*$  is taken as the coherence time. In principle, two pulses separated by  $\tau^*$  suffer a correlation loss of 4dB (10 log 10 .4) relative to a constant channel.

# 3. Consequences of Phase Modulation on the MACS Coherence Time

Phase modulation of the MACS data would occur if either the interplatform distance varied or if the time-of-arrival correction algorithm was unsuccessful. This section first shows the consequences of a general phase modulation under the assumption that the medium itself is time invariant. Then the specific case where the phase modulation is sinusoidal is examined. Realistic examples are given in which coherence times comparable to those of the MACS data are obtained solely due to inter-platform motion or correction errors.

Consider the situation where the actual response function,  $H_n(o)$ , of the acoustic channel is time invariant.

<sup>\*</sup> Bottom center (Plot C) in References 1 and 2.

$$H_{\Omega}(o) = H(o) \tag{3.1}$$

for all n in the data interval. Let the measured channel be the product of the actual response function with a sequence of complex numbers  $\mathbf{z}_n$  over the same interval

$$\hat{H}_{n}(o) = H(o)z_{n} \tag{3.2}$$

Then the normalized time correlation function,  $\rho_{H\bar{H}}(1)$  is simply the normalized auto-correlation function of the sequence  $z_{_{\bar{L}}}$ ,  $\rho_{_{\bar{Z}\bar{Z}}}(1)$ .

$$\rho_{HH}(i) = \frac{\sum_{j=0}^{K-1} H(o)z_{j} (H(o)z_{j+1})^{*}}{\sum_{j=0}^{K-1} |H(o)|^{2}|z_{j}|^{2}}$$
(3.3)

$$= \rho_{iz}(1)$$
 (3.4)

That is, if the channel is time invariant, but subject to a modulating sequence  $\mathbf{z}_n$ , the measured coherence time is effectively that of the modulating sequence.

- (U) For convenience, the continuous time equivalents of the preceding functions will be considered. Since adequacy of the MACS sampling technique is not in question, no difficulty need arise.
- Assume z(t) is a sinusoidally phase modulated waveform:

$$z(t) = e^{-\frac{1}{p}h_p} \cos (2\pi t/T_p)$$
 (3.5)

where  $h_p$  is the maximum phase excursion in radians and  $T_p$  is the period of the modulating waveform. Since z(t) is periodic of period  $T_p$ ,  $\rho_{zz}(\tau)$ 

will also be periodic of period TD.

The normalized autocorrelation of z(t),  $\rho_{zz}(\tau)$  is then given by

$$\rho_{zz}(\tau) = \frac{1}{T_p} \int_{-T_p/2}^{+T_p/2} z(t) z^*(t+\tau) dt$$
 (3.6)

$$= \frac{1}{T_{p}} \int_{-T_{p/2}}^{+T_{p/2}} e^{jh_{p}} \cos \frac{2\pi t}{T_{p}} - jh_{p} \cos \frac{2\pi (t+\tau)}{T_{p}} dt (3.7)$$

From trignometric identities (Reference 5, No. 4.3.37) the exponent can be simplified.

$$h_p \left[\cos \frac{2\pi t}{T_p} - \cos \frac{2\pi (t+\tau)}{T_p}\right] = -2 h_p \sin \frac{2\pi t}{T_p} \sin \frac{\pi \tau}{T_p}$$
 (3.8)

Then

$$\rho_{zz}(\tau) = \frac{1}{T_p} \int_{-T_p/2}^{+T_p/2} e^{-j(2 h_p \sin \frac{\pi \tau}{T_p}) \sin \frac{2\pi t}{T_p}} dt \qquad (3.9)$$

$$= J_o \left( 2h_p \sin \frac{\pi \tau}{T_p} \right)$$
 (3.10)

where  $J_0(u)$  is the zero-th order Bessel function of the first kind and the transition from Equation 3.9 to Equation 3.10 is by Lommel's formula (Reference 5, No. 9.1.21).  $J_0(u)$  is a decaying, oscillatory function of u as shown in Reference 5, Figure 9.1. Thus for a simple model of the phase modulation, an analytic result for the time correlation function is obtained.

The MACS coherence time,  $\tau^*$ , then satisfies

$$.4 = J_o (2h_p \sin \pi \tau^*/T_p)$$
 (3.11)

From linear interpolation of the Table 9.1 of Reference 5,

$$2 h_{\rm p} \sin \pi \tau^*/T_{\rm p} = 1.696$$
 (3.12)

for Equation 3.11 to be valid, that is  $h_p \ge .848$ . If  $h_p < .848$ , then  $\rho_{HH}(\tau)$  never goes as low as .4 and consequently no MACS coherence time can be defined. This result indicates the model is applicable only for maximum phase excursions greater than .848 radians (48.6°).

If  $h_p \ge .848$  radians, Equation 3.12 can be solved to yield the MACS coherence time  $\tau^*$ :

$$\tau^* = \frac{T_p}{\pi} \arcsin \left( \frac{.848}{h_p} \right) \quad (h_p \ge .848)$$
 (3.13)

No small angle approximations have been made up to this point. If  $\tau^*/T_p$  is less than .1, then the small angle approximation sinu = u provides a more convenient form of Equation 3.13.

$$\tau^* = .270 \, {}^{\text{T}}_{\text{p}}/h_{\text{p}} \qquad \frac{(h_{\text{p}} \ge .848)}{(\tau^*/\bar{T}_{\text{p}} < .2)} \qquad (3.14)$$

The second condition of Equation 3.14 will be satisfied if  $h_p \ge 2.70$ ; which also satisfies the first condition. Thus the sinusoidal phase modulation model gives  $\tau^*$  explicitly in terms of the modulation parameters  $h_p$ ,  $T_p$  provided  $h_p$  is greater than 2.70 radians (155 degrees).

(C) Two potential sources of phase modulation must be considered in interpreting the MACS data. First, the intervessel distance might be

modulated by the helmsman or currents. Second, the time of arrival compensation algorithm may introduce significant phase errors at relatively short periods. The MACS data contained in References 1 through 4 does not discuss of the sensitivity of the coherence time measurements to these effects, nor does the presented data contain sufficient results to resolve these issues. The paragraphs below apply the trivial model given above to each situation and show that under realistic assumptions, the MACS coherence times could be determined by either effect. Obviously, other modulating waveforms, such as random noise, could be studied, however the discussion here will be instructure by itself.

Consider the situation in which one of the platforms follows a sinusoidal track about a specified heading and the other platform maintains its heading exactly. The inter-platform distance, y(t), will then be sinusoidally modulated. Let

$$y(t) = \frac{a_{max}}{2\pi} v T_{p} \cos 2\pi t/T_{p} + d$$
 (3.15)

where  $a_{max}$  is the maximum heading error in radians, v is the vessel speed and  $T_p$  is the period of the vessel motion. The maximum heading error,  $a_{max}$ , is the largest angle between the actual and intended track, when the small angle assumption tan  $\theta = \theta$  is made. The maximum phase excursion,  $h_p$ , is then

$$h_{\mathbf{p}} = a_{\max} \cdot \mathbf{v} \quad \mathbf{T}_{\mathbf{p}} \quad \mathbf{f}_{\mathbf{0}/c} \tag{3.16}$$

where  $f_0$  is the center frequency and c is the speed of sound.

The MACS coherence time,  $\tau^*$ , can be calculated from Equation 3.14

$$\tau^* = \frac{.270 \text{ c}}{a_{\text{max}} \text{ v f}_0}$$
 (3.17)

provided that  $h_p \ge 2.70$  and  $a_{max}$  is small  $(a_{max} < \pi/10)^*$ . For the 5 kt vessel speed and 500 Hz center frequency of the MACS data:

$$h_p = .015 a_{max}^0 \cdot T_p$$
 (3.18)

where  $a_{max}^{0}$  is the maximum heading error in <u>degrees</u>. If  $a_{max}^{0} \cdot T_{p} \ge 180$ , then  $h_{p} > 2.70$  and Equation 3.17 gives a coherence time  $\tau^{*}$  of

$$\tau^* = \frac{18.3}{a_{\text{max}}^0} \tag{3.19}$$

For a maximum heading error of two degrees and a motional period greater than 180 seconds Equation 3.19 yields a coherence time of 9.2 seconds, which is within the range of the MACS results. Heading errors of this magnitude are apparently not unusual.

The second potential source of phase modulation of the MACS data is the time of arrival compensation. Inspection of the "Reception Time" plots included in References 2 through 4 indicates substantial variance in the arrival time relative to the quantization step of 4.096 ms (720°). Because the scaling of both axes of these plots is automatically selected, this variance is sometimes difficult to judge.

Dr. Freese has indicated that the quantity labeled "Residual" in the lower center of theseplots (Reference 4 only) is the root mean

<sup>\*</sup> For convenience take c = 5000 ft/sec, 1 kt = 1.689 ft/sec.

squared difference between the measured arrival time and the arrival time estimated by the curve-fitting algorithm in milliseconds. Over the 84 time arrival plots of Reference 4, this quantity has a mean value of 6.3 milliseconds with a minimum of .95 ms (Blake 5/5) and a maximum of 22.5 ms (Shelf North 50/15). Translated into phase at 500 Hz, the "residual" has a mean of 3.08 cycles, a min imum of 167°, and a maximum of 11 cycles. Moreover, 53% of the plots have "residuals" greater than 720°, only 17% have residuals less than 360°. Consequently the effects of the time of arrival compensation algorithm are worth considering.

The difference between the measured and fitted arrival time is not sinusoidal, as can be seen from any of the "Reception Time" plots. If the actual arrival time is smoothly varying, however, the difference between the actual and fitted arrival times could appear sinusoidal. Under these conditions the model given earlier provides insight. Let E be the error between the actual and fitted arrival times. Then h p is given by

$$h_p = 2\pi f_0 E$$
 (3.20)

and

$$\tau^* = .043 \frac{T_p}{E \cdot f_o}$$
 (3.21)

where  $h_{n} \ge 2.70$  must hold to apply Equation 3.21.

At 500 Hz, Equation 3.20 becomes

$$h_p = 3.14 E_{ms}$$
 (3.22)

where  $\rm E_{ms}$  is the error expressed in milliseconds. The condition for Equation 3.21 will be met if  $\rm E_{ms}$  > .86 ms. Equation 3.21 is then

$$\tau^* = .086 \frac{T_p}{E_{ms}} \tag{3.23}$$

Assume that  $T_p$  is of the order of the interval size (300 seconds) divided by the degree of the fitting polynomial (4), that is 75 seconds. Then a one millisecond error between the actual and fitted arrival times yields a coherence time of 6.5 seconds. This is also within the range of the MACS coherence times.

The preceding discussion clearly does not prove that the MACS coherence time measurements result from either platform motion or time of arrival compensation errors. It does show, however, that these effects must be understord to properly interpret the MACS data.

# 4. Phase modulation of large TW systems

If inter-platform motion was the dominant factor in the MACS collegence time measurement, the same phase modulation will be present in large TW systems. The effect of this modulation on system performance will depend on the system center frequency,  $f_o$ , the signal duration,  $T_B$ , and the specific motional waveform. In this section, the performance of a large TW system under the sinusoidal phase modulation of the preceding section will be examined. The results of this examination show that the MACS coherence time  $\tau^*$  is not the limiting value for  $T_B$  and that large TW systems have considerable resistance to such phase modulation. Further, the apparent differences in coherence

times measured by the MACS project (References 1 through 4) and those of the ACS project (References 6 and 7) will be explained.

- For convenience, the M7 pseudo noise burst communications system and specifically its synchronization/channel response measurement algorithm will be considered. The analysis will be equally applicable to the periodic pseudorandom sequence techniques which have found wide application by ONR transmission measurement investigators.
- Let a(t), |a(t)| = 1, be the transmitted pseudonoise burst waveform of duration  $T_B$  in the probe component of the M7 system. In the system bandwidth, a(t) is white

$$R_{aa}(\tau) \sim T_B \delta(\tau)$$
 (4.1)

For pseudonoise systems with TW products greater than 1000, Equation 4.1 is an excellent approximation.

Assume the received signal, y(t), is the sinusoidally phase modulated response of a linear, time invariant channel, c(t), to the transmitted waveform, a(t).

$$y(t) = e^{\int h_p \cos \frac{2\pi(t + t_o)}{T_p}} \int a(u) c (t - u) du$$
 (4.2)

Here  $h_p$  is the maximum phase excursion in radians,  $T_p$  is the motional period and  $t_o$  indicates the starting time of the burst relative to the motional period. Although y(t) will have a longer time duration than a(t) due to the channel, its duration will still be of the order of  $T_p$ .

.

Before proceeding further, observe that if the burst duration  $T_B$  is small relative to the motional period,  $T_p$ , the phase modulation appears as a simple frequency shift. Assume  $T_B < \frac{T}{p}/10$ , then the small angle approximations sin u = u,  $\cos u = 1$  applied to Equation 4.2 yield

$$y(t) \sim e^{-\int h_{p} \sin \frac{2\pi t_{o}}{T_{p}} \frac{2\pi t}{T_{p}} + h_{p} \cos \frac{2\pi t_{o}}{T_{p}}} \int_{a(u)c(t-u)du} (4.3)$$

$$T_{B} < T_{p}/10$$

The first term in the exponent represents a pure frequency shift, the second represents a constant phase shift. A large TW system, such as the M7 communication system, includes automatic Doppler removal algorithms and would compensate for the motional effects under the assumption. The constant phase shift term would have no effect at all. Consequently, motional effects are important for large TW systems only when the burst duration  $T_B$  is near the motional period  $T_p$ .

The estimated channel response,  $\hat{c}(t)$ , is obtained by cross-correlating y(t) with a replica of the transmitted signal, a(t)

$$c(t) = \int_a^{\pm} (v)\dot{y} (v+t)dv \qquad (4.4)$$

$$= \int a^{*}(v) e^{\int \frac{t^{2}}{p} \cos 2\pi (t_{0} + t + u)} a(u)c(v+t-u)du dv \qquad (4.5)$$

Let v - u = w, then

$$\hat{c}(t) = \int c(t + w) R_{aa} (-w, h_p, t_o, +t, T_p) dw$$
 (4.6)

where

$$R_{aa}(-w, h_p, t', T_p) = \int_e^{-\frac{t}{2}} \int_e^{-\frac{2\pi(t'+u)}{T_p}} a(u)a^*(u+w)du$$
 (4.7)

If no interplatform motion is present, then  $h_{p}$  = o and Equation 4.7 becomes

$$R_{aa}(-w, o, t', T_p) = \int a(u)a^*(u+w)du$$
 (4.8)

$$= R_{aa}(w) \tag{4.9}$$

$$\sim T_{B} \delta(w)$$
 (4.10)

Then

$$\hat{c}(t) \sim T_B c(t)$$
 (4.11)

by inserting Equation 4.10 into Equation 4.6. Thus, if no interplatform motion is present, the crosscorrelation procedure of Equation 4.4 gives the channel impulse response c(t) multiplied by a processing gain  $T_B$ .

When  $h_p$  is non-zero,  $R_{aa}(w, h_p, t', T_p)$  may be changed in two ways. First, it may no longer be impulsive as required in Equation 4.1. Second, its peak correlation value may be reduced to less than  $T_B$ . The first change would have the most drastic consequences, but will not occur unless the phase modulation is correlated with the pseudonoise transmission. That is,

$$R_{aa}(w, h_p, \epsilon^1, T_p) \sim 0 |w| > 0$$
 (4.12)

Consequently, the following approximation for  $R_{aa}(w, h_p, t', T_p)$  is appropriate:

$$R_{aa}(w, h_p, t^*, T_p) = z^*(h_p, t^*, T_p) \delta(w)$$
 (4.13)

where

$$z'(h_p, t', T_p) = \int_e^{h_p} \cos \frac{2\pi(t'+u)}{T_p} \alpha$$
 (4.14)

since |a(t)| = 1. The range of integration of Equation 4.14 is over the  $T_B$  long interval where a(t) is non zero. The reduction in  $z(h_p, t', T_p)$  relative to  $T_B$  as a function of the motional parameters  $h_p$ , t' and  $T_p$  is important and will be discussed below.

The following definition will be convenient:

$$z(h, a, b) = \frac{1}{2\pi b} \int_{2\pi a}^{2\pi a + 2\pi b} e^{j2\pi h \cos u} du$$
 (4.15)

The function z(h, a, b) has the following properties:

$$z(h, a, b) \sim 1$$
 small h, all a or small b, all a (4.16)

$$z(h, a + .5, b) = z(h, a, b)$$
 (4.17)

$$z(h, a, .5n) = J_0(2\pi h)$$
 all a and integer n (4.18)

Appendix A gives tables of z(h, a, b) which have been verified via Equation 4.18 to be correct to 3 significant figures. Note that z(h, a, b) is in general complex.

Equation 4.13 can be rewritten in terms of z(h, a, b) as follows:

$$R_{aa}(w, h_p, t', T_p) = z(h, a, b) \cdot T_B \delta(w)$$
 (4.19)

where

$$h = h_{p/2\pi} \tag{4.20}$$

$$a = t'/T_{p} \tag{4.21}$$

$$b = T_B/T_D \tag{4.22}$$

Thus z(h, a, b) can be interpreted as the loss factor, relative to  $T_B$ , for a phase modulation parameterized by h, a and b. Here h represents the maximum phase excursion in cycles and equals the maximum spatial excursion in wavelengths. The parameter a gives the initial angle in cycles and b is the burst duration normalized by the national p-riod.

Define the loss due to motion, L(h, a, b) as follows:

$$L(h, a, b) = -10 \log_{10} |z(h, a, b)|^2$$
 (4.23)

This is the loss in signal to noise ratio experienced by the cross-correlation process expressed in decibels. In an actual system, the initial angle a would not be known, hence the following loss,  $L_{\max}$ , is of more value in system design:

$$L_{\text{max}}(h, b) = \frac{\text{max}}{0 \le a \le .5}$$
 L(h, a, b) (4.24)

That is,  $L_{max}$  is the maximum loss over all initial angles for a given h and b. Figure 4.1 depicts lines of constant  $L_{max}$  over the h, b plane. For small h or for small b  $L_{max}$  is small as expected.

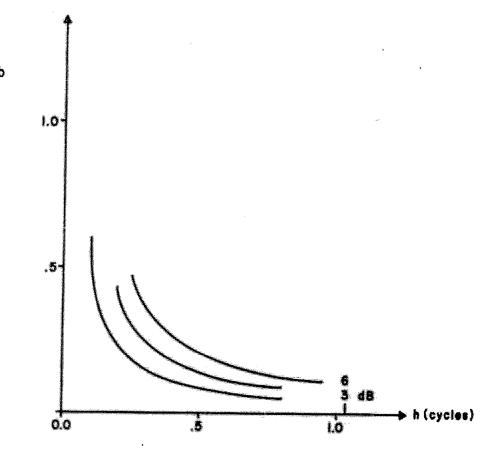


Figure 4.1: Lines of Constant L<sub>MAX</sub> (This figure

The preceding analysis is immediately applicable to the synchronization and channel measurement processes in the M7 communication system. The effect of interplatform motion on the information demodulation process deserves further study, but appears to be small compared to the former. The loss experienced by the M7 synchronization and channel measurement processes will be equal to L(h, a, b), but the performance measure  $L_{max}(h, b)$  is more convenient.

From Figure 4.1, curves of constant  $L_{max}(h, b)$  are seen to be nearly hyperbolic, that is,

$$h \cdot b = K_{\mathsf{T}} \tag{4.25}$$

for a specified loss  $L_{max}(h, b)$  in decibels. This approximation fails for small h, as a specified  $L_{max}(h, b)$  may not occur for any b below a given value of h, designated  $h_L^*$ . That is, given a loss L,

$$L_{\text{max}}(h, b) < L$$
 for all b (4.26)  
if  $h < h_{L}^{*}$ 

Table 4.1 gives  $K_L$  and  $h_L^*$  for L=1, 3, 6 and 10 dB. Further, for b < .1 the system's automatic Doppler removal algorithm will remove the motional effects as indicated in Equation 4.3. Subject to these constraints, Equation 4.25 provides insight into the M7 system performance.

Table 4.1.	Limiting value	s of h
	(This Table	
Loss L, dB	K <sub>L</sub>	<u>h.*</u>
1.	,044	.05
3.	.073	.15
6.	.109	.20
10.		.25

From Equations 3.16 and 4.20,

$$h = \frac{a_{\text{max}}}{2\pi c} \quad \nabla \quad T_{p} \quad f_{o} \tag{4.27}$$

then Equation 4.25 becomes

$$\frac{a_{\text{max}} \text{ v f}_{\text{o}} \text{ T}_{\text{B}}}{2\pi \text{ c}} = \text{K}_{\text{L}}$$
 (4.28)

where bwas found from Equation 4.22. This gives a convenient relation between the platform motion indicated by  $a_{max}$  and v and the burst characteristics  $T_B$  and  $f_o$ . For example, consider the 5Kt vessel speed and 2° heading error assumed in the preceding section. In order for the M7 system to have less than a 3 dB loss, the following relation from Equation 4.28 must hold:

$$f_0 \cdot T_B \le 7775$$
 (4.29)

At the current M7 center frequency of 204.8 Hz, this requires that  $T_{\rm B} \leq 40$  sec. At the 500 Hz center frequency of the MACS data,  $T_{\rm B} \leq 15.5$  sec. Note carefully that Equation 4.28 is valid only where the loss

curves are hyperbolic; that is,  $h > h_L^*$ , b > .1.

Equation 4.28 can be exploited further making use of Equation 3.17 to relate the MACS coherence time  $\tau^*$  to  $a_{max}$ .

$$\frac{.270}{2\pi} \frac{T_{B}}{\tau^{*}} = K_{L} \tag{4.30}$$

This can be rewritten to yield

$$T_n = 1.7 \quad \tau^*$$
 (4.31)

Here the value of  $K_L$  corresponding to a 3 dB loss has been taken from Table 4.1. Equation 4.31 holds only if the conditions of Equation 3.17 are valid,  $h_p \ge 2.70$  (h > .430),  $a_{max}$  small. The conditions of Equation 4.25, b > .1,  $h > h_{3dB}^* = .15$ , must also hold. The important result is that the burst duration corresponding to a 3dB loss,  $T_B$  by Eq. .ion 4.31, is larger than the MACS coherence time  $\tau^*$  by 70%, under the sinusoidal phase modulation model. Consequently, the MACS coherence time by itself does not determine the time duration for a large TW system, even under an elementary motional model.

- The preceding analysis is also helpful in understanding the coherence times measured by the ACS project as described in References 6 and 7. These results indicate the medium decorrelates approximately 3 dB in 210 seconds, but the measurement technique is significantly different from the MACS project.
- In the ACS technique, channel impulse response measurements  $\hat{c}_i(t)$  are computed from several disjoint input signal vectors  $x(t+iT_B)$ ,  $0 \le t < T_B$ , i=0, 1..., using a large TW product wave-

form. The normalized crosscorrelation function  $\rho_{\dot{1}}(\tau)$  is computed for each interval  $\dot{i}>0$ .

$$\rho_{i}(\tau) = \frac{1}{\left|\hat{c}_{o}(t)\right|^{2} dt \left|\hat{c}_{i}(t)\right|^{2} dt} \int c_{o}^{*}(t)\hat{c}_{i}(t+\tau)dt \qquad (4.32)$$

In general  $\rho_{\mathbf{i}}(\tau)$  is complex. Then the following correlation coefficient is found.

$$\rho_{\underline{i}} = \max_{\tau} |\rho_{\underline{i}}(\tau)| \tag{4.33}$$

The purpose of the maximumization is to eliminate the effects of time of arrival changes between the o-th and i-th interval. Plots of  $\rho_i$  versus the time offset, iT $_B$ , are generated and the coherence time is found by interpolation of the resulting plots. The processing also employs a Doppler removal algorithm.

Because motional effects reduce the size of  $\hat{c_i}(t)$  by  $z(h_i, a_i, b_i)$  and do not change its shape, the normalization indicated in Equation 4.32 eliminates the motional effects completely. Indeed if  $c_i'(t)$  is the actual channel response in the ith interval then

$$\rho_{i}(\tau) = \rho_{c_{0}^{i}c_{i}^{*}}(\tau) \tag{4.34}$$

that is,  $\rho_{1}(\tau)$  is the normalized cross correlation for the actual channel. The only consequence of the interplatform motion will be in the reduction of the signal to noise ratio in the estimated channel response  $\hat{c}_{1}(t)$ . All ACS measurements included algorithms which calculated  $\rho_{1}(\tau)$  only if both

 $\hat{c}_{o}(\tau)$  and  $\hat{c}_{i}(\tau)$  had signal to noise ratios greater than 10 dB. Thus the ACS coherence time measurements are insensative to motional effects.\*

### 5. Conclusions and Recommendations

- The MACS coherence time measurement is sensitive to both interplatform motion and errors in arrival time compensation. Under the assumption of a sinusoidal variation in interplatform distance with a maximum heading error of 2° on one platform the coherence time is limited to 9.2 seconds even if the medium is actually time invariant. Similarly a 1 millisecond error in arrival time with a period of 75 seconds yields a maximum coherence time of only 6.5 seconds. Since both of these results are in the same range as those of the MACS data, the MACS coherence times may be attributable more to platform motion or the time of arrival compensation technique than to actual changes in the acoustic medium.
- If the MACS coherence times are highly influenced by interplatform motion, these motional effects must be understood in detail to design improved communication systems. Ideally, continuous and coherent data on interplatform motion should be obtained. This data should be capable of indicating fractional wavelength variations in distance and could be obtained by coherent demodulation of a tonal component in the transmission. Unfortunately, the MACS data lacks such a component and the

All ACS experiments had transmissions with substantial carrier lines. Consequently, information on interplatform motion could be obtained by analysis of carrier phase.

necessary information on vessel motion may not be obtainable from the existing data.

Performance of large TW product systems, such as the M7 communication system, depends on the specifics of the interplatform motion. For the sinusoidal distance variation considered here, the large TW systems are less sensitive to motional effects than the MACS measurement technique. For example, under the same conditions a large TW system can use a burst duration 70% larger than the MACS coherence time and achieve only a 3 dB loss. If the motional period is large relative to the burst duration, the losses are even smaller.

The following recommendations are offered based on the above results. First, recipients of References 1 through 4 should be advised that the coherence times reported may be due to platform motion or time of arrival compensation error. Such a notice is needed because the MACS documents do not consider these effects and represent the coherence time as a measurement of the medium itself. Second, the MACS data should be reprocessed to extract better information on interplatform motion, if that is possible. Third, future MACS experiments should include a tonal component adequate to resolve interplatform motions.

## REFERENCES

- Freese, H. A., Description of Processing of MACS Sea Trip Data, Naval Underwater Systems Center, New London, Connecticut, 06320, TM No. 771198, 23 Sept. 1977.
- Ellinthorpe, A. W. and H. A. Freese, MACS Transmission Data: Results from the June 1976 Sea Trip (U), Naval Underwater Systems Center, New London, Connecticut 06320, TM No. 771061 (two parts), 23 Sept. 1977. (CONF).
- Ellinthorpe, A. W. and H. A. Freese, MACS Transmission Data: Results from the November 1976 Sea Trip (U), Naval Uederwater Systems Center, New London, Connecticut, 06320, TM No. 781050 (two parts), 7 March 1978. (CONF).
- Ellinthorpe, A. W., H. A. Freese and G. J. O'Brien, MACS Transmission Data: Results of the January 1977 Sea Trip (U). Naval Underwater Systems Center, New London, Connecticut, 06320, TM No. 781194 (three parts), 13 Oct. 1978. (CONF).
- Abramowitz, M. and I. A. Stegum, <u>Handbook of Mathematical Functions</u>, National Bureau of Standards, Applied Mathematics Series, No. 55, U.S. Government Printing Office, Washington, D.C. 20402, June 1964.
- Kimball, C. V., Acoustic Communication Studies (U), Journal of Defense Research, Series B: Tactical Warfare, Vol. 7B, No. 2, Advanced Research Projects Agency, Washington, D.C., Summer 1975. (CONF).
- Kimball, C. V., Personal Communication to Dr. A. O. Sykes, Office of Naval Research, Code 222, dated 27 May 1976.

## APPENDIX A

TABLE OF Z (h,a,b)

η = .1, (.1), 1. a = worst a for a = 0., (.05), .45 b = .05, (.05), 1

THIS TABLE IS

DELTA = 0.010000

H, A, AND B IN TABLE BELOW ARE IN FRACTIONS OF A CYCLE. H = 0.63 RADIANS. FIRST LOSS ENTRY IS MAXIMUM LOSS, SECOND IS AVERAGE LOSS OVER A, A = 0. , I \* 0.050 , 0.450

Н	AMAX	8	ZR	21	MAG Z	ANG Z	/Z/¥¥2	1.08	S(DB)
0.10	0.250	0.050	0.804	-0.572	0.987	-35.4	0.974	-0.1	-0.1
0.10	0.200	0.100	0.817	-0.581	1.003	-35.4	1.005	-0.0	-0.0
0.10	0.200	0.150	0.824	-0.561	0.997	-34.3	0.594	-0.1	-0.1
0.10	0.150	0.200	0.848	-0.530	1.000	-32.0	1,000	-0.2	-0.1
0.10	0.150	0.250	0.867	-0.479	0.991	-28.9	9.982	·-0.3	-0.2
0.10	0.100	0.300	0.886	-9.416	0.979	-25.1	0.958	-0.5	-0.2
0.10	0.050	0.350	0.904	-0.342	0.967	-Z0.7	0.935	-0.5	-0.3
0.10	0.050	0.400	0.910	-0.265	0.947	-16.2	0.897	-0.7	-0.4
0.10	0.000	0.450	0.911	-0.187	0.930	-11.6	0.864	-0.8	-0.4
0.10	0.000	0.500	0.903	-0.116	0.911	-7.3	0.829	-0.9	-0.5
0.10	0.450	0.550	0.897	-0.052	0.898	-3.3	0.807	-0.9	-0.6
0.10	0.450	0.600	0.889	0.000	0.889	0.0	0.790	-1.0	-0.7
0.10	0.450	0.650	0.885	0.040	0.886	2.6	0.785	-1.1	-0.7
0.10	0.400	0.700	0.887	0.068	0.890	4.4	0.792	-1.1	-0.8
0.10	0.400	0.750	0.891	0.082	0.895	5.3	0.801	-1.1	-0.8
0.10	0.350	0.800	0.899	0.083	0.903	5.3	0.815	-1.0	-0.8
0.10	9.350	0.850	0.394	0.073	0.907	4.6	0.822	-1.0	-0.9
0.10	0.300	0.500	0.906	0.053	0.508	3.4	0.824	-1.0	-0.3
0.10	0.250	0.950	0.907	20 V V V V V V V V V V V V V V V V V V V	0.907	1.8	0.823	-0.9	-0.9
0.10	0.250	1.000	0.903	0.000	0.903	0.0	0.816	-0.9	-0.9
								72.5.7%	

TABLE OF Z(H,A,B) - 08 MAY 79

DELTA = 0.010000

H, A, AND B IN TABLE BELOW ARE IN FRACTIONS OF A CYCLE. H = 1.26 RADIANS. FIRST LOSS ENTRY IS MAXIMUM LOSS, SECOND IS AVERAGE LOSS OVER A. A = 0. , 1 \* 0.050 , 0.450

	1.8	**************************************							- fair is
H	XAMA	8	ZR	21	MAG Z	ANG Z	/Z/ <b>XX</b> 2	Los	S(DB)
0.20	0.250	0.050	0.324	-0.932	0.987	-70.8	0.973	-0.2	-0.1
0.20	0.200	0.100	0.329	-0.347	1.003	-70.8	1.005	-0.2	-0.1
0.20	0.200	0.150	0.364	-0.926	0.995	-68.5	0.550	-0.5	-0.3
0.20	0.150	0.200	6.434	-0.891	0.991	-64.0	0.982	-0.8	-0.4
0.20	0.150	0.250	0.513	-0.818	9.966	-57.9	0.932	-1.3	-0.7
0.Z0	0.100	0.300	0.588	-0.714	0.925	-50.6	0.855	-1.8	-0.9
0.20	0.050	0.350	0.645	-0.584	9.871	-42.2	0.758	-2.2	-1.2
0.20	0.050	0.400	0.668	-0.445	0.803	-33.7	9.645	-2.8	-1.5
0.20	0.000	0.450	0.666	-0.309	0.734	-24.9	0.538	-3.3	-1.9
0.20	0.000	0.500	0.642	-0.189	9.679	-16.4	0.448	-3.8	-2.2
0.20	0.450	0.550	0.614	-0.085	0.620	-7.8	0.385	-4.2	-2.5
0.20	0.450	0.600	0.590	0.000	0.590	0.0	0.348	-4.6	-2.8
0.20	0.450	0.650	0.578	0.068	0.532	6.7	0.339	-4.7	-3.0
9.26	0.499	0.700	9.583	0.119	0.595	11.5	0.354	-4.9	-3.3
0.20	0.400	0.750	0.599	0.147	0.617	13.8	0.380	-4.8	-3.5
0.20	0.350	0.800	0.624	. 0.159	0.641	13.5	0.411	-4.8	-3.6
0.20	0.359	0.850	0.643	0.130	0.656	11.4	0.431	-4.5	-3.7
0.20	0.300	0.500	0.654	9,093	0.660	8.:	0.436	-4.4	-3.8
0.20	0.250	0.550	0.653	0.047	0.655	4.1	0.429	-4.1	-3.8
0.20	0.250	1.000	0.642	0.000	0.642	0.0	0.413	-3.8	-3.8

DELTA = 0.010000

H, A, AND B IN TABLE BELOW ARE IN FRACTIONS OF A CYCLE. H = 1.88 RADIANS. FIRST LOSS ENTRY IS MAXIMUM LOSS, SECOND IS AVERAGE LOSS OVER A. A = 0. , I \* 0.050 , 0.450

н	AMAX	В	2R	ZI	MAG Z	ÀNG Z	/Z/**2	LO	55( DB )
0.30	0.250	0.050	-0.275	-0.947	0.986	-106.2	0.973	-0.2	
0.30	0.200	0.100		-0.962		-106.2	1.005	-0.5	
0.30	0.200	0.150		-0.968		-102.8	0.985	-1.1	
0.30	0.150	0.200		-0.971	0.977	Control of the Contro	0.954	30.00	
0.30	0.150	0.250	The state of the s	-0.924	0.925	THE STATE OF THE STATE OF	0.855	-2.0	
0.30	0.100	0.300		-0.817	9.840	-7E.7	0.705	-3.0	
0.30	0.050	0.350		-0.660	0.726	-65.3	0.527	-4.3	-2.2
0.30	0.050	0.400	100	-0.485	0.596	-54.6	Ø.355	-5.5	-2.9
0.30	0.000	0.450		-0.323	0.464	-44.0	50 (Complete Professor)	-7.9	-9.7
0.30	0.000	0.500	0.291	-0.192	0.349	100 ACC 100 AC	0.216	-8.7	-4.6
0.30	0.450	0.550		-0.036	0.253	-33.5	0.122	~10.7	-5.5
0.30	0.450	0.600	0.196	0.000	37.78%	-19.9	9.064	-11.9	-6.3
0.30	0.450	0.650		9.975	0.196	0.0	0.038	-14.2	-7.2
0.30	0.400	0.700			0.188	29.6	0.035	-14.5	-8.0
0.30	0.400	9.750		9.140	0.226	38.2	0.051	-16.3	-8.7
0.30	0.350	1.60 360 - 5075-03	0.209	0.189	0.275	40.7	0.076	-15.3	-9.3
0.30	0.350	0.800	0.256	0.107	0.316	36.1	9.100	-15.7	-3.8
	100	0.850	0.295	0.159	0.335	28.3	0.112	-14.1	-10.2
0.30	0.300	0,506	0.315	0.169	<b>.</b> 233	19.2	0.111	-13.3	-10.5
0.30	0.250	0.950	0.311	9.052	0.316	3.5	0.100	-11.8	-10.7
0.30	0.250	1.000	0.291	0.000	0.231	0.1	0.084	-10.7	-10.7
TABLE O	10 Professional Control				v-cu:	<b>V.1</b>	0.004	-10.7	-19.7

DELTA = 0.010000

H, A, AND B IN TABLE BELOW ARE IN FRACTIONS OF A CYCLE. H = 2.51 RADIANS. FIRST LOSS ENTRY IS MAXIMUM LOSS, SECOND IS AVERAGE LOSS OVER A. A =  $0.71 \pm 0.050$ , 0.450

н	AMAX	B	ZR	21	MAG Z	ANG Z	/2/**2	Lös	5(DB)
0.40	0.250	0.050	-0.773	-0.612	0.986	-141.6	0.972	-0.3	-0.2
0.40	0.200	0.100	-0.786	-0.622	The Section Section (Contraction)	-141.6	1.004	-0.9	-0.4
0.40	0.200	0.150	-0.724	-0.673	THE RESERVE OF THE PARTY OF THE	-137.1	0.578	-2.0	-1.0
0.40	0.150	0.200	-0.593	-0.751	Control of the Contro	-128.3	0.916	a.c-	-1.8
0.40	0.150	0.250		-0.776	22.1	-116.8	0.756	-5.6	-2.9
0.40	0.100	0.300	The second second second	-0.709	0.00	-104.2	0.535	-8.5	-4.2
0.40	0.050	0.350	and the second second second second second	-0.554	0.555	-92.3	0.308	-11.8	-5.8
0.40	0.050	0.400	Company Tox September	-0.376	per per seen that make a	-85.2	0.142	-17.8	-7.7
0.40	0.000	0.450		-0.224	0.224	-88.4	0.050	-22.8	
0.40	0.000	A CONTRACTOR OF THE PARTY OF TH	And the second Capacitan Street	-0.124	25 100 100 100 100 100 100 100 100 100 10	-113.7	100 100 100 100 100 100 100 100 100 100	0.000	-9.8
0.40	0.450			-0.056		Control of the Contro	0.018	-25.3	-10.5
0.40	0.450	and the second s	-0.176	The second residence of the second se	A SECTION OF THE PROPERTY OF T	-155.5	810.0	-17.4	-10.0
0.40	0.450	The second second second	-0.209		0.176	180.0	0.031	-15.1	-9.9
9.40	9.400	A SECTION OF SECTION O	A STATE OF THE STA	and the second second	0.218	164.1	0.047	-13.2	-10.1
9.40	- Condition Indian Residence	- Care Co. 42 84 88 8 18 4 18 18 18 18 18 18 18 18 18 18 18 18 18	-0.209	0.126	0.244	148.9	0.059	-12.5	-10.8
	0.450		-0.168	0.176	0.243	133.6	0.059	-12:3	-11.8
0.40	0.150	Con-Alice Str. Mark 1985	-0.100	0.188	0.213	117.9	9.045	-13.9	-13.4
9.40	0.100		-0.042	0.156	0.161	105.0	0.026	-17.4	-15.7
6.40	0.050		-0.016	0.098	0.100	99,5	0.010	-22.6	-19.1
0.40	0.000	0.950	-0.026	0.041	0.049	122.1	0.002	-28.7	-23.7
0.46	0.000	1.000	-0.055	0.000	0.055	179.7	6.003	-25.3	-25.2

TABLE OF Z(H,A,B) - 98 MAY 79

DELTA = 0.010000

H, A, AND B IN TABLE BELOW ARE IN FRACTIONS OF A CYCLE. H = 3.14 RADIANS. FIRST LOSS ENTRY IS MAXIMUM LOSS, SECOND IS AVERAGE LOSS OVER A. A = 0. , 1 \* 0.050 , 0.450

Н	AMAX	В	ZR	<b>Z1</b>	MAG Z	ÀNG	Z	/Z/ <b>**</b> 2	L05	S(DB)
0.50	0.250	0.050	-0.984	-0.051	0.986	-177	. 0	0.972	-0.5	-0.3
0.50	0.200	3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1		-0.052	1.002	-177	. 0	1.003	-1.4	-0.7
0.50	0.200	100 PM	ALCOHOLOGICAL CONTROL	-0.147	0.984	-171	. 4	0.968	-3.2	-1.6
0.50	0.150	1 of 10 and 10 and 2 and 10 an		-0.310	0.932	-160	. 5	0.868	-6,1	-3.0
0.50	0.150	En contracting to the Contraction of the Contractio	200 200 200 200 200 200 200 200 200 200	-0.437	6.803	-147	. 0	0.645	-9.9	-4.8
0.50	0.100	The second secon	The state of the s	-0.440	0.610	-133	. 8	0.372	-17.2	-7.4
0.50	0.050			-0.312	0.393	-127	.4	0.154	-25.7	-10.7
0.50	0.050	- The State Control of the Control o	PC: - Paul Administration (Pared Ones)	-0.155	0.246	-140	. 8	0.060	-17.7	-9.8
0.50	0.000			-0.049	0.241		0.00	0.058	-12.8	-8.8
0.50	0.000		-0.304		0.394	LEAD PROPERTY.	25636	0.092	-10.3	-8.3
0.50	0.350	55-7673-551	-0.369		0.369	San Service and the		0.136	-8.9	-8.2
7. 198.41	0.250	79.88	-0.420		0.420	180	48.00	0.176	-8.9	-8.3
0.50 0.50	0.200	AN CHESTON	-0.458		0.459	176	2010876	0.211	-11.3	-8.8
	9.150	(Sinc. 10)	-0.468	0.081	0.475	170		0.226	-14.7	-9.5
0.50	Manual State	100000000000000000000000000000000000000	-0.428		2.449	162	95 (6)	0.202	-15.4	-10.2
0.50	0.150	7.7.7.900		0.153	0.381	:55	·	0.145	-16.6	-10.5
0.50	0.100	315 255 38 38	-0.347		3.303	156		0.092	-14.5	-10.5
0.50	9.400		-0.277	0.123	3.261	165	300	0.068	-12.9	-10.4
0.59	C.050	0.900		0.064		176	Company of the	0.074	-11.4	-10.4
0.50	9.000	257 S. T. S. T. SETTING.	-0.271	0.018	9.272	- T- 1997	77	0.092	-10.3	-10.3
0.50	0.000	1.000	-0.304	0.000	0.304	130	.0	0.0JE	-19.0	

TABLE OF Z(H,A,B) - 08 MAY 79

DELTA = 0.010000

H, A, AND B IN TABLE BELOW ARE IN FRACTIONS OF A CYCLE. H = 3.77 RADIANS. FIRST LOSS ENTRY IS MAXIMUM LOSS, SECOND IS AVERAGE LOSS OVER A. A =  $\theta$ ., I \*  $\theta$ .050 ,  $\theta$ .450

H	AMAX		ZR	21	MAG Z	ANG Z	/Z/##2	Los:	S(DB)
0.60	0.250	0.050	-0.832	0.528	9.585	147.6	9.971	-0.6	-0.4
0.60	0.200	0.100	-0.845	0.537	1.001	147.6	1.002	-2.1	-1.0
0.60	0.200	0.150	-0.882	0.424	0.978	154.3	0.957	-4.8	-2.4
0.69	0.150	0.200	-0.879	0.202	0.902	167.0	0.814	-9.7	-4.6
0.60	0.150	0.250	-0.728	-0.025	0.728	-178.0	0.530	-17.8	-8.0
0.60	0.100	0.300		-0.109	0.490	-167.2	0.240	-23.9	-10.8
0.60	0.000	0.350		-0.018	0.296	-176.5	0.087	-14.1	-9.2
0.60	0.000	0.400	-0.273	0.101	0.292	159.7	0.085	-10.8	-8.2
0.60	0.000	0.450		0.141	0.368	157.4	0.136	-8.9	-7.7
0.50	0.000	Street, to the street of	-0.402	0.107	0.416	165.0	9.173	-7.5	-7.5
0.60	0.200	0.550		0.048	0.446	173.8	0.199	-9.4	-7.7
0.60	0.200	0.600		-0.000	0.475	-180.0	0.226	-12.7	-8.1
0.50	0.200		-0.512		0.513	-178.3	9.263	-14.0	-8.4
0.60	0.150		-0.538	0.018	0.538	178.0	0.290	-14.1	-8.4
0.60	0.150	0.750		0.080	0.517	171.1	0.267	-12.2	-8.2
0.60	0.050	at the first that was a first the second	-0.423	A CONTRACTOR OF STREET	0.442	165.9	0.195	-10.8	-8.1
100 100 100	0.150	0.850		0.071	0.365	168.8	0.133	-10.0	-8.0
9.60		1000	-0.345	0.015	0.345	177.5	0.119	-9.3	-8.0
0.60	0.150	0.900	144 S. C. C.	-0.011	0.373	-178.4	0.139	-8.6	-7.9
0.60 0.60	0.100	0.950		-0.000	4.1	-180.0	0.161	-7.9	-7.9

DELTA = 0.010000

H, A, AND B IN TABLE BELOW ARE IN FRACTIONS OF A CYCLE. H = 4.40 RADIANS. FIRST LOSS ENTRY IS MAXIMUM LOSS, SECOND IS AVERAGE LOSS OVER A. A = 0. , I \* 0.050 , 0.450

н	AMAX	В	ZR	ZI	MAG Z	ANG Z	/Z/##2	LOS	5(DB)
0.70	0.250	0.050	-0.372	0.912	0.985	112.2	0.970	-0.8	-0.5
0.70	0.200	0.100	-0.377	0.927	1.001	112.1	1.001	-2.9	-1.4
0.70	0.200	0.150	-0.486	0.841	0.971	120.0	0.944	-6.5	-3.4
0.70	0.150	0.200	-0,608	0.620	0.868	134.5	0.754	-15.6	-6.9
0.70	0.150	0.250	-0.561	0.326	0.649	149.8	0.421	-24.7	-11.3
0.70	0.050	0.300	-0.351	0.174	0.391	153.6	0.153	-14.2	-9.4
0.70	0.050	0.350	-0.196	0.233	0.304	130.1	0.093	-10.5	-8.2
0.70	0.050	0.400	-0.218	0.310	0.379	125.1	0.144	-9.5	-7.6
0.70	0.000	0.450	-0.302	0.280	0.412	137.2	0.170	-9.0	-7.6
0.70	0.000	0.500	-0.342	0.185	0.389	151.6	0.152	-9.3	-7.9
0.70	0.200	0.550	-0.346	0.083	0.356	166.5	0.127	-11.8	-8.4
0.70	0.200	0.600	-0.348	-0.000	0.348	-180.0	0.121	-13.8	-8.7
0.70	0.200	0.650	-0.375	-0.052	0.379	-172.1	0.143	-12.0	-8.8
0.70	0.100	0.700	-0.418	-0.045	0.421	-173.8	0.177	-10.8	-8.8
0.70	0.050	0.750	-0.415	0.014	0.415	178.0	0.173	-10.7	-8.5
9.70	0.000	0.800	-0.344	0.050	0.348	171.7	0.121	-11.1	-9.0
0.70	0.200	0.850	-0.282	0.013	0.283	177.3	0.080	-11.0	-9.1
0.70	0.450	0.500	-0.287	-0.035	0.283	-173.1	0.084	-10.8	-9.2
0.70	8.488	0.950	-0.323	-0.036	0.325	-173.7	0.106	-10.2	-9.3
0.70	0.100	1.000	-0.342	-0.000	AND DESCRIPTION OF THE PROPERTY OF THE PROPERT	-179.9	0.117	-9.3	-9.3

TABLE OF Z(H,A,B) - 98 MAY 79

DELTA = 0.010000

H, A, AND B IN TABLE BELOW ARE IN FRACTIONS OF A CYCLE. H = 5.03 RADIANS. FIRST LOSS ENTRY IS MAXIMUM LOSS, SECOND IS AVERAGE LOSS OVER A. A = 0. , I \* 0.050 , 0.450

H	AMAX	8	ZR	21	MAG Z	ANG Z	/Z/**2	Los	S(DB)
0.80	0.250	0.050	0.225	0.958	€.984	76.8	0.968	-1.0	-0.6
0.80	0.200	0.100	0.229	0.973	1.000	76.7	1.000	-3.9	-1.9
0.80	0.200	0.150	0.073	0.961	0.964	85.6	0.929	-9.7	-4.7
0.80	0.150	0.200	-0.168	0.814	0.831	101.6	0.690	-34.1	-11.2
0.80	0.050	0.250	-0.251	0.512	0.570	116.1	0.325	-16.5	-10.0
0.80	0.000	0.300	-0.105	0.320	0.337	108.2	0.113	-11.6	-8.5
0.80	0.050	0.350	0.003	0.365	0.365	89.5	0.134	-10.3	-7.9
0.80	0.050	0.400	-0.070	0.407	0.413	99.8	0.171	-11.4	-8.0
0.80	0.000	0.450	-0.161	0.320	0.358	116.7	0.129	-12.5	-6.6
0.80	0.000	0.500	-0.169	0.195	0.258	131.0	0.066	-15.4	-9.6
0.80	0.450	0.550	-0.132	0.087	0.158	146.7	0.025	-16.0	-10.6
0.80	0.450	0.600	-0.103	-0.000	0.103	-180.0	0.011	-19.8	-11.5
0.80	9.459	0.650	-0.113	-0.072	0.134	-147.4	0.018	-17.5	-11.9
0.80	0.400	0.700	-0.168	-0.034	0.193	-150.8	0.037	-18.2	-12.7
0.80	0.400	0.750	-0.196	-0.941	0.201	-168.1	0.040	-15.2	-13.4
0.80	0.450	0.800	-0.143	0.001	0.143	179.4	0.021	-16.9	-14.0
0.80	0.450	0.850	-0.098	-0.036	9.104	-159.8	0.011	-19.6	-14.6
0.80	0.200	0.900	-0.125	-0.073	9.144	-149.7	0.021	-19.4	-15.1
0.80	0.150	0.950	-0.165	-0.653	0.172	-163.Z	0.030	-17.5	-15.3
0.80	0.150	1.000	-0.169	-0.000	0.169	-179.8	0.029	-15.5	-15.5

DELTA = 0.010000

H, A, AND B IN TABLE BELOW ARE IN FRACTIONS OF A CYCLE. H=5.65 RADIANS. FIRST LOSS ENTRY IS MAXIMUM LOSS, SECOND IS AVERAGE LOSS OVER A. A = 0., I \* 0.050 , 0.450

н	AMAX	B	ZR	21	MAG Z	'ANG Z	/Z/**2	LOS	S(DB)
0.90	0.250	0.050	0.735	0.650	0.983	41.4	0.967	-1.2	-0.7
0.90	0.200	0.100	0.750	0.660	0.999	41.3	0.998	-5.1	-2.5
0.90	0.200	0.150	0.597	0.745	0.955	51.3	0.512	-13.7	-6.4
0.90	0.200	0.200	0.289	0.736	0.790	68.6	0.625	-21.5	-11.2
0.90	0.050	0.250	0.083	0.490	0.497	80.3	0.247	-12.9	-9.2
0.90	0.100	0.300	0.160	0.295	0.335	61.5	0.112	-11.3	-8.3
0.30	0.050	0.350	0.219	0.350	0.413	58.0	0.170	-12.7	-8.4
0.90	0.050	0.400	0.099	0.358	0.381	,74.9	0.145	-17.6	-9.6
0.30	0.000	0.450	0.018	0.248	0.249	86.0	0.062	-22.0	-11.5
0.90	0.000	0.500	0.045	0.132	0.139	71.2	0,019	-27.0	-12.5
0.90	9.450	0.550	0.110	0.059	0.125	28.2	0.016	-13.1	-12.0
0.90	0.450	0.600	0.163	-0.000	0.162	-0.0	0.026	-15.8	-12.3
8.90	0.400	0.550	0.173	-0.870	0.185	-22.2	0.035	-14.6	-13.4
0.90	0.250	0.700	0.115	-0.116	0.164	-45.2	0.027	-18.0	-15.2
0.90	9.000	0.750	0.053	-0.076	0.095	-52.8	0.909	-21.3	-17.2
0.90	0.400	0.350	0.090	-0.028	0.054	-17.5	0.009	-22.7	-18.8
3.20	0.350	0.850	0.117	-0.066	0.134	-29.6	e.018	-27.3	-19.7
0.80	0.300	0.500	2.065	-e.cee	6.114	-52.5	0.013	-38.7	6.1S-
0.56	0.000	0.950	. 5 1000 5000	-2.049	0.058	-56.6	0.003	-29.0	-24.7
0.30	9.250	1.000		-0.000	0.045	-0.5	0.002	-27.0	-26.9

TABLE OF Z(H,A,B) - 08 MAY 79

DELTA = 0.010000

H, A, AND B IN TABLE BELOW ARE IN FRACTIONS OF A CYCLE. H = \$.28 RADIANS. FIRST LOSS ENTRY IS MAXIMUM LOSS, SECOND IS AVERAGE LOSS OVER A. A = 0. , I \* 0.050 , 0.450

Н	AMAX	В	ZR	21	MAG Z	ANG Z	/2/**2	Los	S(DB)
1.00	0.250	0.050	0.977	0.102	0.983	6.0	0.966	-1.5	-0.8
1.00	0.200	0.100	0.993	0.103	0.998	5.9	0.997	-6.5	-3.1
1.00	0.200	0.150	0.904	0.275	0.945	16.9	0.894	-20.4	-8.5
1.00	0.050	0.200	0.612	0.430	0.748	35.1	0.559	-17.1	-10.3
1.00	0.000	0.250	0.324	0.292	0.436	42.0	0.190	-11.9	-8.8
1.00	0.100	0.300	0.346	0.125	0.368	19.9	0.135	-13.6	-8.7
1.00	0.050	0.350	0.366	0.209	0.422	29.7	0.178	-18.7	-10.2
1.00	0.050	0.400	0.217	0.215	0.306	44.7	0.093	-31.5	-12.6
1.00	0.000	0.450	0.163	0.092	0.187	29.3	0.035	-17.3	-11.5
1.00	0.000	0.500	0.220	0.021	0.221	5.3	0.049	-13.2	-10.9
1.00	0.350	0.550	0.292	0.009	0.292	1.8	0.085	-11.2	-10.8
1.00	0.100	0.500	0.349	-0.000	0.349	-0.0	0.122	-12.1	-11.3
1.00	0.100	0.650	0.378	-0.047	0.381	-7.1	0.145	-15.5	-12.0
1.00	0.250	0.700	0.332	-0.108	0.350	-18.6	0.122	-15.2	-12.2
1.00	0.150	0.750	0.255	-0.084	0.268	-18.2	0.072	-15.1	-12.4
1.00	0.100	0.800	0.269	-0.034	0.271	-7.Z	0.074	-19.3	-12.9
1.00	0.100	0.850	0.281	-0.074	0.290	-14.7	0.084	-19.1	-13.3
1.00	0.050	0.900	0.213	-0.084	0.235	-21.1	0.055	-17.4	-13.3
1.00	0.000	0.950	0.193	-0.033	0.196	-9.7	0.038	-14.9	-13.Z
1.00	0.000	1.000	0.220	-0.000	0.220	-0.0	0.048	-13.2	-13.1

# APPENDIX B

DR. ELLINTHORPE'S REPLY

BY MUTUAL AGREEMENT, THE LETTER
GIVEN IN THIS APPENDIX IS CLASSIFIED



# NAVAL UNDERWATER SYSTEMS CENTER HEADQUARTERS NEWPORT, RHODE ISLAND 02840

NEWPORT, R. I. 02840 AREA CODE 401 841 – EXT. AUTOVON 948 + EXT. NEW LONDON, CONN, 96320 AREA CODE 203 442 – 0771 – EXT. AUTOVON 636 + EXT. 4179

in REPLY REFER TO: 3103:AWE:bj 9460/MACS Ser 93103-67 8 June 1979

Dr. Christopher V. Kimball University of Miami School of Marine and Atmospheric Science 4600 Rickenbacker Causeway Miami, Florida 33149

Ref: (a) "Comments on the MACS Coherence Time Measurements" by C. V. Kimball dated 21 May 1979

(b) Your letter dated 22 May 1979

#### Dear Chris:

- This is a response to reference (a) which was forwarded by reference (b).
- The MACS measurements were undertaken with the foreknowledge that they could examine only limited regions of the multi-dimensional space which is needed to describe underwater acoustic propagation, but with the expectation that the results could be extended by physical explanations to span the global regions of interest for tactical ship to ship links. The reports cited by reference (a) are deliberately restricted in their contents to a recitation of the empirical results; the generalizations through physical theories cannot be conducted on a piecemeal basis but must incorporate the whole of the data and a great deal of other work besides, and that phase of the work is far from complete.
- Reference (a) deals with only one parameter, time coherence; asserts the reported results to be due to either platform motion or improper processing procedures; proposes that a cautionary statement be distributed to warn of there "defects"; and asserts that the inclusion of tone transmissions would have remedied the matter.
- My first concern is the narrowness of reference (a)'s considerations in both its overall viewpoint and in several of its details. The history of underwater sound work is bedevilled by similar failures to confront the fact that the processes being studied result from a complex coupling of many effects whose disentanglement is a difficult and delicate task; to overlook that coupling is an impermissible and grossly misleading simplification.
- For example, the restriction of interest to time coherence leads to reference (a)'s recommendation that tones be included as a means of cleansing the MACS defects. They were in fact included but the results have not been

3103:AWE:bj 9460/MACS Ser 93103-67

- reported because of the obscurity of their significance, a property which is a consequence of the inability to discern multipath effects in tone data. In other words, the time and frequency domains cannot be decoupled. This disagreeable fact is reflected in the prescriptions of channel characterization theory which are that measurement probes can be constructed of sequences of pulses, or groups of tones, or their union in the form of pseudo-noise; and the three are formally equally efficient. (It was convenient to use pulses in the MACS work.)
- Reference (a) is, of course, correct in pointing out that platform motion perturbations contribute to the observed coherence time results. Other contributions, ignored by reference (a), are; the modulations imposed by reflection from a stormy surface; the effects of platform motion coupling with scattering (from rough bottom topography, from within bottom sediments, or from within the volume); and the effects of internal wave motion. Our responsibility is to define all of these contributions quantitatively, in both physical terms and in their effects on system performance.
- As a matter of possible interest, platform motion perturbations are caused by helmsman behavior and are frustratingly non-stationary, depending on the time within the watch and on the particular watchstander. The worst case magnitude is about 1° to 2° rms (as reference (a) correctly assumes) with a time constant of about 100 seconds. That magnitude is similar to the magnitude of the minimum spread induced by a single reflection from a rough bottom. (The minimum occurs at the extreme range attainable by a single reflection where the grazing angle is minimized.) Multiple bottom reflections (encountered at greater ranges) or steep angle reflections (encountered at shorter ranges) produce larger spreads by a factor of two or more. The time constant of the bottom reflection process is about two orders of magnitude shorter than that of the motional perturbations at speeds and frequencies of operational interest. The surface induced effects are even worse.
- Thus, reference (a) is broadly correct in its discussion of the effects of motional perturbations, but in ignoring the other more important phenomena it misrepresents reality; motional perturbations are a minor factor.
- In the matter of the procedures used to remove the gross motional effects, reference (a)'s algebra is correct but its premises aren't. The issue (not addressed by reference (a)) is a problem inherent to measurements made between moving ships, the situation that the Navy is all about. It is that the velocity vectors cannot be closely controlled; the two ships can find themselves in different current fields, or have different gyro errors, or have different errors in their speed sensors. As a result, the path length varies in both a stochastic manner and, as a result of corrective action by the receiving ship (where bearing and travel time information are available), in a deterministic manner. The time scales associated with these trends are in the hundreds of seconds whereas thousands of seconds of data are needed to obtain adequately low variance estimates of the propagation parameters.

3103:AWE:bj 9460/MACS Ser 93103-67

- Thus the trends have to be removed, and in a way which doesn't corrupt the results. The procedure that has been followed has been to fit a polynomial to the arrival times, and a key issue is the choice of time constant for the polynomial. If it is too small then some of the real propagation changes will be inadvertently removed, and if it is too large then spurious doppler effects will be leaked into the data. The time constant has been chosen at around 100 seconds, in part on the twin grounds that it is smaller than the gross path length changes and is of the order of the time duration of operational use for either tactical communications or echo ranging.
- The notion of transit time in a fading channel is beset by the problem that in the presence of a fade there can be no definition of any such quantity. The issue is a fundamental one, having to do with the definition of group or energy velocity which itself collapses at transmission nulls. (Stratton's book treats the matter carefully.) Thus a plot of arrival time is, by any measure, certain to exhibit spikes whenever the signal amplitude falls to zero. One cannot in fact speak of anything more than the arrival time obtained by averaging over some suitable interval because, in general, the several modes fade independently. The choice of about 100 seconds in the fitting procedure was therefore based on having many pulse arrivals to form this average, in addition to the other considerations cited earlier.
- Reference (a) ignores these points and assumes that the variance in the arrival time estimates represents an error in fitting procedure and, having set up that straw man, proceeds to show that such an error would be intolerable. Of course it would be, but it is not such an error and reference (a)'s discussion of this matter is thus irrelevant.
- In addition to the above generalities, reference (a) contains a number of particular points that are objectionable:
  - In the sentence which begins at the foot of page 1 and terminates at the top of page 2 it is asserted that -- "a large TW system offers significant (↑ 10 dB) performance advantages --". The basis for this remark is unclear. The criterion for gauging system performance is commonly accepted to be the minimization of the energy required to transmit a unit of information, and that criterion is not satisfied by maximizing the single parameter, integration time. Even in that simplistic case the unique figure 10 dB is not discernible; the allowable coherent time is simply inversely proportional to center frequency and there are no discontinuities.
- The last sentence of the first complete paragraph on page 2 says that - 'a more suitable transmission waveform -- ' will be suggested. As explained earlier this is a false claim.

3103:AWE:bj 9460/MACS Ser 93103-67

- In the paragraph at the top of page 3 and in several subsequent paragraphs mention is made of the fact that the sampling interval was equivalent to 2 carrier periods at 500 Hz. This citation appears to reflect an ignorance of the sampling theorem; the sampling rate was 2.5 times the bandwidth. (It was also equivalent to 20 carrier periods at 5000 Hz, a number that is more striking than 2.)
- The discussion of section 4 shows that a slowly varying phase modulation is easily overcome. This is true but irrelevant because of the other time constants already noted.

Sincerely,

A. W. ELLINTHORPE

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